# Department of Defense
# Legacy Resource Management Program

PROJECT 07-290

**QUANTIFYING IMPACTS OF GROUND WATER WITHDRAWAL ON AVIAN COMMUNITIES IN DESERT RIPARIAN WOODLANDS OF THE SOUTHWESTERN U.S.**

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# Quantifying impacts of ground water withdrawal on avian communities in desert riparian woodlands of the southwestern U.S.

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## EXECUTIVE SUMMARY

Riparian woodlands in the desert southwest are an extremely important resource because they constitute <1% of the desert landscape, yet typically support >50% of the breeding birds. Riparian woodlands also provide shelter and critical food resources for dozens of species of Neotropical migratory birds that alight in these woodlands during their spring and fall migrations across the desert southwest. Ground water withdrawal (and subsequent loss of surface water) to support urban developments in the desert southwest has the potential to degrade or eliminate riparian woodlands throughout the region, including riparian woodlands along the Upper San Pedro River adjacent to Fort Huachuca Military Reservation in Arizona. Military readiness could be jeopardized if limited military resources are diverted from the military's mission at Fort Huachuca Military Reservation (and at other military installations in the southwestern U.S.) to deal with the recovery of potentially dozens of declining populations of birds. The objective of this ongoing research project is to assess the value of riparian woodlands to the health and persistence of avian communities in the desert southwest. Specifically, we seek to quantify the extent to which both surface water and the health of riparian vegetation influence the abundance and diversity of riparian birds in the region. From March to September 2006 and 2007, we surveyed birds, sampled vegetation, and measured surface water at 23 study sights located in riparian woodlands throughout southeastern Arizona, including several study sites situated along the Upper San Pedro River near Fort Huachuca Military Reservation. We also sampled avian food resources (i.e., aerial arthropods) and monitored nests of riparian bird species at a subset of these study sites. We used multiple linear regression to conduct a spatial analysis examining the role of surface water and the health of riparian vegetation on bird parameters while controlling for potentially confounding variables such as vegetation structure and composition. We also used linear regression to conduct a temporal analysis using data from a subset of 10 study sites sampled in both 2006 and 2007. We found that the presence and extent of surface water was positively associated with the total relative abundance of riparian birds and with the relative abundance of 4 bird species: Black Phoebe, Vermillion Flycatcher, Northern Beardless-tyrannulet, and White-winged Dove. Sampling of potential avian food resources at a subset of study sites indicated that aerial arthropod biomass averaged 89% greater at "wet" versus "dry" study sites. We also found that Vermillion Flycatchers, Common Yellowthroats, and House Finches were negatively associated with the presence and extent of dead or dormant riparian vegetation at our study sites. We believe that riparian bird communities along the Upper San Pedro River (and elsewhere in the desert southwest) are threatened in 2 ways by future ground water loss. First, should ground water levels fall to the point where surface water flows are reduced or eliminated, populations of bird species such as Black Phoebe, Vermillion Flycatcher, Northern Beardless-tyrannulet, and White-winged Dove are likely to decline. Second, should ground water levels fall to the point that riparian vegetation is strongly effected, populations of many other bird species, including birds like Vermillion Flycatchers, Common Yellowthroats, and House Finches are likely to decline. Continued drought conditions in the desert southwest are likely to compound problems associated with ground water withdrawal in the foreseeable future. This report summarizes results from the first 2 years of a 3-year study funded, in part, by the DOD Legacy Resource Management Program.

## INTRODUCTION

Riparian woodlands in the desert southwest (Fig. 1) are an extremely important resource because they constitute less than 1% of the desert landscape yet typically support greater than 50% of the breeding birds (Fig. 2; Johnson et al. 1977). Riparian woodlands also provide critical stopover habitat for hundreds of migratory bird species (Skagen et al. 1999). The high species richness of birds in riparian woodlands relative to surrounding vegetative communities is commonly attributed to the structural complexity of the vegetation (Anderson and Ohmart 1977, Bull and Skovlin 1982, Knopf and Samson 1994). However, the surface water itself may be equally or more important because riparian areas with standing or flowing surface water support higher densities of invertebrate prey. Little is known about the role that surface water itself plays in determining the relative value of riparian woodlands to birds in the desert southwest. If surface water directly enhances the value of riparian woodlands for birds, even relatively small reductions in the ground water table may have large repercussions on abundance and species composition of the avian community. Recent droughts and increasing water needs of a growing human population are leaving many areas in the region more and more reliant on ground water.

The Upper San Pedro River, adjacent to Fort Huachuca Military Reservation and the City of Sierra Vista, Arizona, is the southwest's largest undammed river and supports one of the largest riparian woodlands in the southwestern U.S (Krueper 2003). Over 300 species of birds (including approximately 100 breeding and 250 migrant species) have been recorded in these riparian woodlands. Almost all of these species are protected under the Migratory Bird Treaty Act. Ground water withdrawal to support Fort Huachuca and the growing development associated with the City of Sierra Vista and Cochise County has the potential to degrade or even destroy the riparian woodlands along the Upper San Pedro River. Besides the Upper San Pedro River, rapidly expanding human populations near other important riparian areas in the southern Arizona (e.g., Rincon Creek near Tucson, Santa Cruz River near Green Valley) have the potential to negatively impact riparian woodlands throughout the region. Other military bases in the southwestern U.S. have riparian woodlands (e.g., Fort Hood) or are located adjacent to areas with riparian woodlands (e.g., White Sands Missile Range) and may face similar problems in the foreseeable future. The loss or degradation of riparian woodlands throughout the desert southwest is a serious and growing threat to numerous species of birds that depend on these areas for breeding, wintering, and/or migratory habitat.

As part of a regional ecosystem initiative, Arizona Partners in Flight has identified low-elevation riparian woodland as a top priority habitat in need of conservation because it contains a tremendous diversity of birds and because it is severely threatened (Latta et al. 1999). Three bird species that inhabit low-elevation riparian habitat are considered Arizona Partners in Flight priority species of conservation concern: Southwestern Willow Flycatcher (*Empidonax traillii extremus*), Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*), and Lucy's Warbler (*Vermivora luciae*). The Southwestern Willow Flycatcher is federally listed as endangered and the western Yellow-billed Cuckoo is a candidate for listing. Both species are found breeding along the Upper San Pedro River and in other riparian woodlands in southern Arizona. An additional eight species that inhabit low-elevation riparian woodlands are considered Arizona Partners in Flight preliminary species of conservation concern. These species include the Brown-crested Flycatcher (*Myiarchus tyrannulus*), Northern Beardless-

Figure 1. Typical riparian vegetation along Bonita Creek (top photo) and Cienega Creek (bottom photo), southeastern Arizona. The tree species visible in the photographs are Fremont cottonwood (*Populus fremontii*), Goodding willow (*Salix gooddingii*), and velvet ash (*Fraxinus velutina*).

Fig. 2. Two relatively-common bird species, the yellow-breasted chat (top photo) and the Bell's vireo (bottom photo), that breed in low-elevation riparian woodlands in southeastern Arizona (Photos by B. Taubert).


Tyrannulet (*Camptostoma imberbe*), Bell's Vireo (*Vireo bellii*), Yellow Warbler (*Dendroica petechia*), Rufous-winged Sparrow (*Aimophila carpalis*), Abert's Towhee (*Pipilo aberti*), and Summer Tanager (*Piranga rubra*; Latta et al. 1999).

Efforts to protect the function and sustainability of riparian bird communities in the desert southwest require predictions about the potential effects of ground water withdrawal (and subsequent surface water depletion) on the natural resources in this important vegetation type. Therefore, the goal of this research project is to assess the value of riparian woodlands to the health and persistence of avian communities in the desert southwest. Specifically, we seek to quantify the extent to which surface water and the health of riparian vegetation (i.e., the percentage of vegetation that is dead or dormant) influence the abundance and diversity of riparian birds. Ultimately, our objective is to develop a set of models to allow resource managers on military lands to better predict the ultimate effects of future ground water withdrawal and surface water depletion on riparian bird communities along the Upper San Pedro River and elsewhere in the desert southwest. To facilitate the development of these models, we tested the following statistical hypotheses using data collected in 2006 and 2007.

1) Amount of surface water in the 50 m surrounding a survey point is positively correlated with avian species richness and relative abundance

2) Percentage of vegetation that is dead or dormant riparian in the 50 m surrounding a survey point is negatively correlated with avian species richness and relative abundance

3) Increase in surface water (from 2006 to 2007) in the 50 m surrounding a survey point is positively correlated with an increase in avian relative abundance

4) Arthropod biomass is greater in riparian areas with substantial amounts of surface water compared to riparian areas lacking surface water

5) Clutch sizes and egg volumes are higher in riparian areas with substantial amounts of surface water compared to riparian areas lacking surface water (for a focal species)

Maintaining the health of riparian woodlands (and their associated bird communities) is a top priority for the agencies that are mandated to protect and/or enhance natural resources in the desert southwest. Therefore, we sought to create partnerships among all of the federal agencies, state agencies, local agencies, and non-governmental organizations that have a vested interest in protecting riparian woodlands in the desert southwest during the current study. Loss or degradation of riparian woodlands is an especially important issue for the Department of Defense (DoD) in the desert southwest because ground water withdrawal has the potential to curtail installations' missions and reduce military readiness should ineffective action be taken to protect the health of vulnerable riparian woodlands on or near military bases (e.g., Fort Huachuca, Fort Hood, and White Sands Missile Base). By being able to better predict the effects of ground water withdrawal on bird communities, the DoD and other agencies can work proactively to protect these areas before riparian woodlands become degraded and bird populations become threatened or endangered.

## METHODS

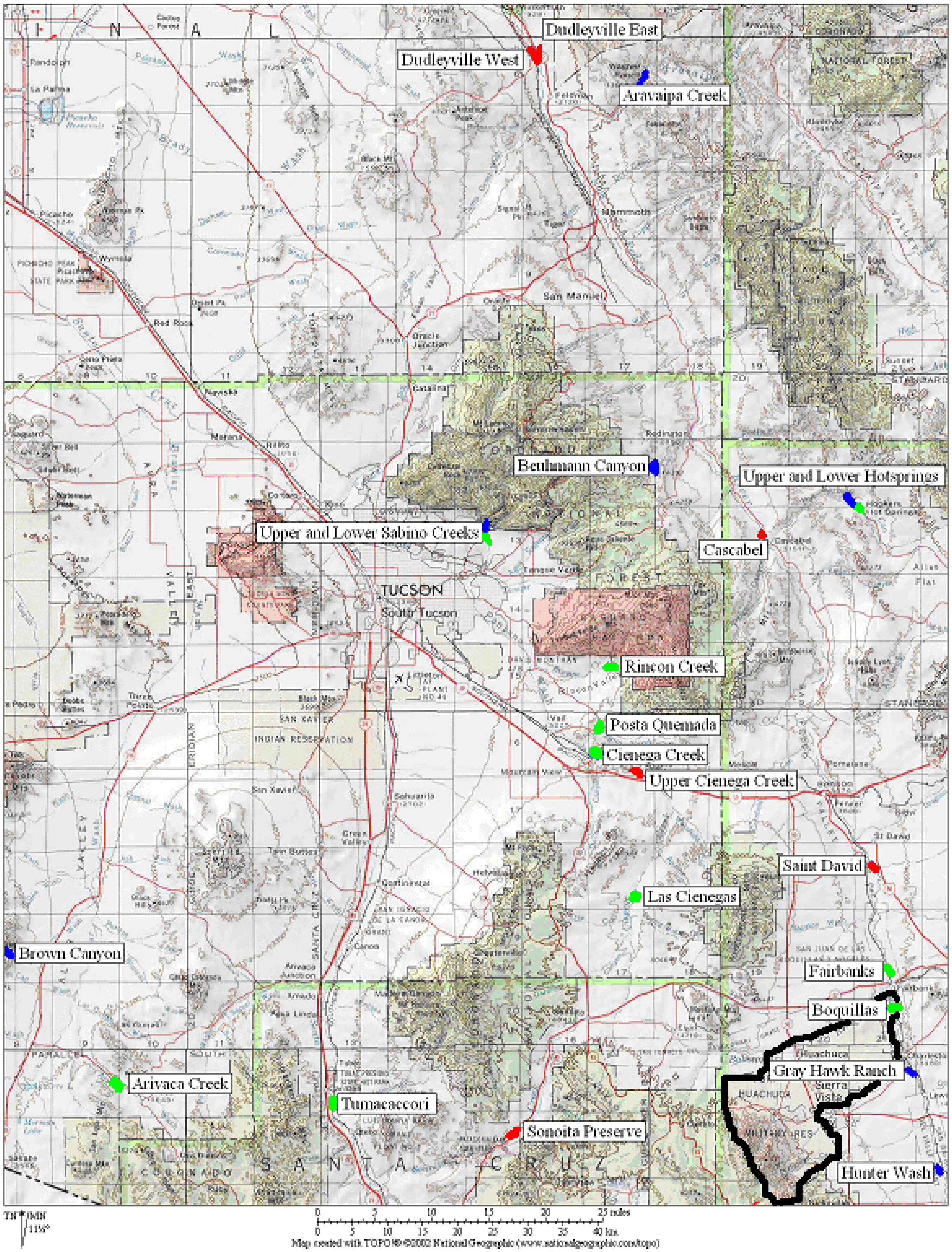
*Study Area*--We conducted this research project in low-elevation riparian woodlands in an area of southeastern Arizona bounded by the Gila River to the North, the Altar Valley to the West, the Mexican border to the South, and the New Mexican border to the East (Fig. 3). The study area straddled the division between the Sonoran Desert to the west and the Chihuahuan Desert to the East and was located between approximately 700 and 1,300 m elevation. Climate in the region is arid/semi-arid with approximately 300 mm of precipitation falling per year in low-elevation areas. Annual precipitation is bimodal with a brief summer season of localized thunderstorms followed by a longer winter season of widespread frontal storms.

Cottonwood-willow (Fig. 1) and mixed-broadleaf riparian forests are the two major low-elevation riparian forest types in the region (Brown 1994). Both forest types are found along perennial and seasonally intermittent streams but cottonwood-willow forest is located primarily on alluvial soils on flood plains whereas mixed-broadleaf forest is located primarily along rubble-bottomed drainages (Brown 1994). Dominant trees in cottonwood-willow forest include Fremont cottonwood (*Populus fremontii*) and Goodding willow (*Salix gooddingii*). Dominant trees in mixed-broadleaf forest include Arizona sycamore (*Plantanus wrightii*), velvet mesquite (*Prosopis velutina*), velvet ash (*Fraxinus velutina*), Arizona walnut (*Juglans major*), Fremont cottonwood, and willows (*Salix* spp.). These riparian forest types are often flanked by mesquite or mesquite-hackberry (*Celtis* spp.) woodlands located in the transitional area between the riparian forest and the surrounding uplands.

*Site Selection*--We used a Geographic Information System (GIS; ArcInfo GIS software, Environmental Sciences Research Institute, Inc. 1999) to select potential sites within our study area that were broadly similar in terms of elevation, topography, and stream order. Using the GIS, we identified all potential sites within our study area that were located between 700 and 1,250 m elevation, that were not located in steep-sided canyons, and that contained streams classified as having stream orders of 4, 5, or 6 (Strahler 1952). We then created a list of these potential study sites ranking sites highly if they were accessible (e.g., not on private land) and were near a USGS well and/or stream gauge. We also consulted with local biologists and hydrologists to ensure that we had not omitted any potential study sites from consideration.

We visited the top 20 potential study sites on our list during the winter/spring of 2006 and 2007 to evaluate their suitability for the study. We wanted the presence and extent of surface water to vary between study sites as well as within study sites (for a subset of sites). Therefore, we sought to determine from the ground, from USGS stream flow records, and from discussions with local hydrologists and biologists whether each potential study site typically had perennial flowing surface water, seasonally or spatially intermittent surface water, or ephemeral surface water (i.e., flowing water present only after precipitation events). Finally, we chose several additional study sites located in riparian woodlands along 2 larger, perennially-flowing streams in southeastern Arizona because of the acknowledged importance of their riparian woodlands to riparian bird communities in the region (Skagen et al. 1999, Krueper 2003). Specifically, we chose 4 study sites along the Upper San Pedro River adjacent to Fort Huachuca Military Reservation, 4 study sites on the Lower San Pedro River, and 1 study site along the Santa Cruz River at Tumacacori National Historical Park (Fig . 3). All told, we selected 7 sites that had

Figure 3. Study area in southeastern Arizona showing the locations of 23 study sites surveyed in 2006 (blue), 2007 (red), and both 2006 and 2007 (green), and the location of Fort Huachuca Military Reservation (bounded by bold black line) adjacent to the City of Sierra Vista and the San Pedro River. See Appendix 1 for detailed maps of each study site.



perennial flowing surface water, 12 sites that had intermittent surface water, and 4 sites that had ephemeral surface water (Table 1; Fig. 3).

*Bird Survey Routes*--At each of the study sites, we established a riparian point-count bird survey route (henceforth "riparian survey route") by using a hand-held Global Positioning System (GPS) receiver to locate survey points at 100-m intervals along a 900-1,500 m section of the stream channel. For larger, perennially-flowing streams, we placed survey points along one side of stream channel only. For smaller streams, we alternated the placement of surveys points from one side of the stream channel to the other along the stream channel (determination of first survey point location decided by coin flip). We changed the location of a survey point to the opposite stream bank if the riparian vegetation was too narrow on the original side (i.e., if >50% of the area within a 50-m radius of the survey point encompassed upland vegetation). We placed each survey point 10 m away from the edge of the high-water channel to ensure that we could hear singing/calling birds above the noise of flowing water (B. Powell, University of Arizona, personal communication).

*Bird Surveys*--Before the start of each field season, we trained and tested field personnel in the identification of southwestern birds (both by sight and sound) and the estimation of distances to objects during a formal 2 week training session. We conducted bird surveys from 1 April to 25 June. We selected this time period based on records of peak breeding activity for common riparian and upland birds found in and near riparian areas in Arizona (Corman and Wise-Gervais 2005). We surveyed birds along each survey route approximately every 3 weeks (total of 4 replicate bird surveys per route per year) and alternated the direction in which we conducted surveys from one visit to the next. Because the probability of detecting birds is negatively correlated with time of day and wind speed, we conducted all bird surveys in the early morning (between sunrise and 2 hours after sunrise) on days without precipitation and with wind speeds <10 km/hr.

We recorded temperature (°C), wind speed (km/hr) using a hand-held anemometer, and % cloud cover at the start and end of each survey along each survey route. Eight observers surveyed birds in 2006 and 5 observers surveyed birds in 2007. To reduce observer bias, we rotated observers during subsequent replicate surveys at all study sites except at the 4 study sites along the Upper San Pedro River where, for logistical reasons in 2006, a single observer conducted all bird surveys. At each survey point, observers waited 1 minute and then begin a count of all birds heard and/or seen during an 8-minute survey period. For each bird detected, observers recorded the species and distance (m) from the survey point to the bird (measured with the aid of an infrared rangefinder). Birds that were detected flying over the survey point were recorded as "flyovers". In addition, observers recorded the 1-minute interval in which each bird was first detected during the 8-minute survey period and the type of detection (visual, auditory, or both).

*Surface Water Sampling*--Once every 3 weeks during the bird breeding season in 2006 and 2007 (following each replicate bird survey), we estimated the presence and extent of surface water within a 50-m radius area surrounding each bird survey point at each study site using the following methods. We first walked the length of the survey route and mapped all flowing water and standing pools of water within approximately 100 m on either side of the survey route. For each standing pool of water, we used a GPS receiver to collect UTM coordinates for the start and

Table 1. Twenty-three study sites used to examine the link between ground water withdrawal and surface water depletion on the health and persistence of riparian bird communities in southeastern Arizona in 2006 and 2007. Study sites are organized by the type of surface flow typical at each site.

| Name of Site | Site Code | Elevation (m) | Administering Agency | # Pts. | Surface Water | Year(s) Surveyed |
|---|---|---|---|---|---|---|
| Aravaipa Creek | ARA | 750 | The Nature Conservancy | 15 | Perennial | 2006 |
| Gray Hawk* | GRA | 1,210 | U.S. Bureau of Land Management | 12 | Perennial | 2006 |
| Lower Hot Springs | LHS | 1,200 | The Nature Conservancy | 15 | Perennial | 2006 |
| Dudleyville West | DUW | 610 | The Nature Conservancy | 15 | Perennial | 2007 |
| Sonoita Creek | SON | 1,215 | The Nature Conservancy | 15 | Perennial | 2007 |
| Boquillas* | BOQ | 1,170 | U.S. Bureau of Land Management | 12 | Perennial | 2006 & 2007 |
| Tumacacori | TUM | 1,005 | National Park Service | 10 | Perennial | 2006 & 2007 |
| Brown Canyon | BRO | 1,000 | U.S. Fish and Wildlife Service | 14 | Intermittent | 2006 |
| Upper Sabino Creek | USA | 850 | U.S. Forest Service | 11 | Intermittent | 2006 |
| Buehman Canyon | BEU | 1,180 | U.S. Forest Service | 15 | Intermittent | 2006 |
| Hunter Wash* | HUN | 1,230 | U.S. Bureau of Land Management | 12 | Intermittent | 2006 |
| Cascabel | CAS | 945 | U.S. Bureau of Land Management | 10 | Intermittent | 2007 |
| St. David | STD | 1,100 | Private Land | 12 | Intermittent | 2007 |
| Fairbanks* | FAI | 1,160 | U.S. Bureau of Land Management | 12 | Intermittent | 2006 & 2007 |
| Rincon Creek | RIN | 965 | National Park Service | 10 | Intermittent | 2006 & 2007 |
| Arivaca Creek | ARI | 1,085 | U.S. Fish and Wildlife Service | 14 | Intermittent | 2006 & 2007 |
| Cienega Creek | CIE | 1,020 | Pima County Parks and Recreation Dept | 15 | Intermittent | 2006 & 2007 |
| Upper Hot Springs | UHS | 1,230 | The Nature Conservancy | 15 | Intermittent | 2006 & 2007 |
| Lower Sabino Creek | LSA | 800 | Private land | 12 | Intermittent | 2006 & 2007 |
| Dudleyville East | DUE | 620 | The Nature Conservancy | 11 | Ephemeral | 2007 |
| Upper Cienega | UCI | 1,075 | Pima County Parks and Recreation Dept | 12 | Ephemeral | 2007 |
| Las Cienegas | LLC | 1,380 | U.S. Bureau of Land Management | 10 | Ephemeral | 2006 & 2007 |
| Posta Quemada | POS | 1,060 | Pima County Parks and Recreation Dept | 9 | Ephemeral | 2006 & 2007 |

* Sites located along Upper San Pedro River adjacent to Fort Huachuca Military Reservation

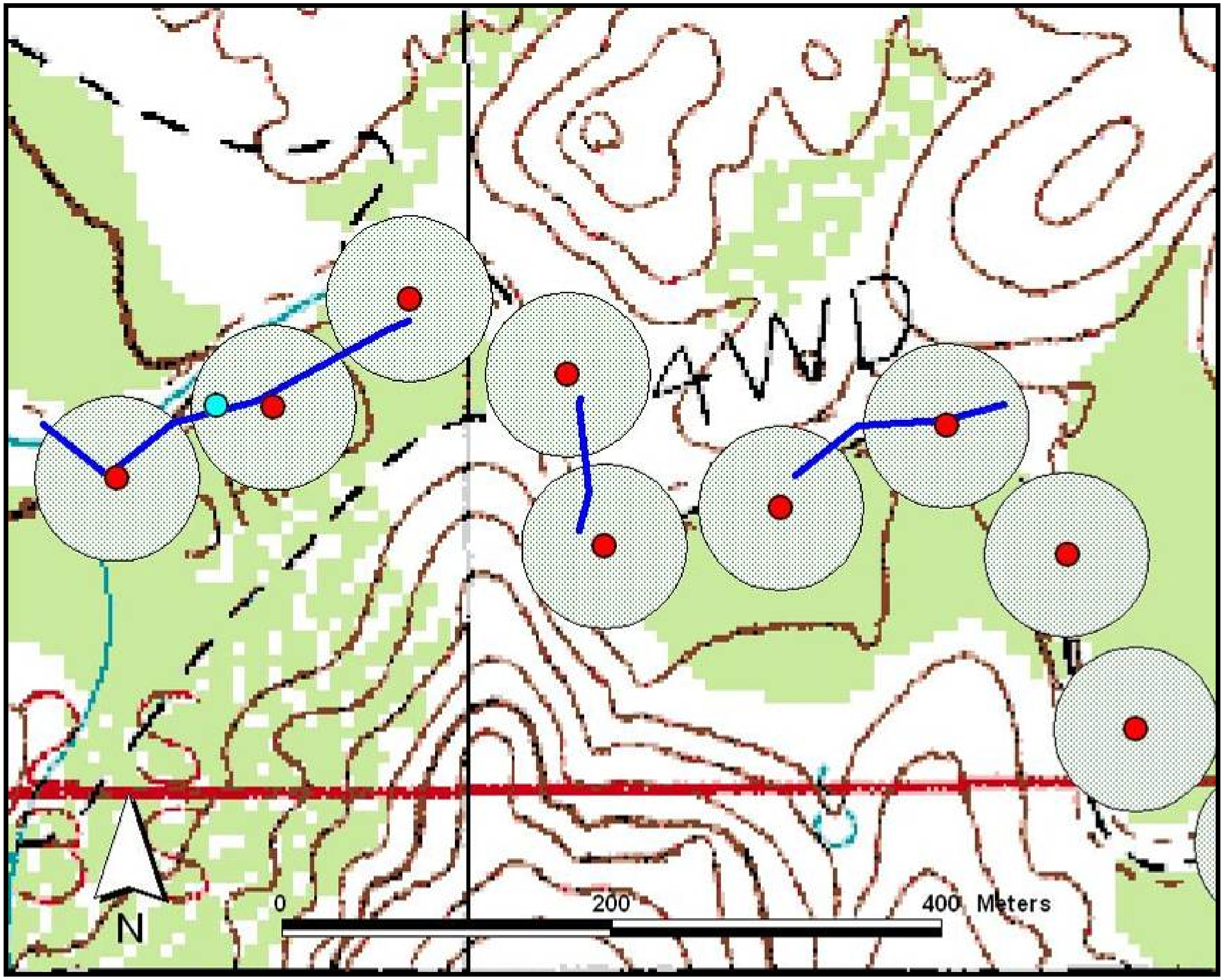
end points of the pool and measured the maximum width and length of the pool using a carpenter's rule or metric tape. For each segment of flowing water, we estimated the length of the segment by collecting UTM coordinates for the start and end points of the segment and measuring the width of water along the stream segment at 50-m increments (or at the segment mid-point for segments <100 m in length). We modified these methods from surface water sampling protocols developed by the National Park Service for use at Rincon Creek (D. Swann, Saguaro National Park, personal communication).

We used a GIS to determine which pools of standing water and what proportion of flowing water segments were within 50 m of each survey point at each study site (Fig. 4). We then calculated the surface area of each pool of standing water using the formula for the surface area of an ellipse (surface area = *Pi* x [0.5 x max. length] x [0.5 x max. width]). We used this formula because an ellipse best approximated the average shape of standing pools of water within our study area. We calculated the surface area for each flowing segment of water within 50 m of each survey point by multiplying the length of the segment by the average of the 2 closest stream width measurements that we collected while in the field at 50 m increments along the segment. We then summed the total area of surface water (from both standing pools and flowing segments of water) across survey points and survey replicates for each study site.

*Vegetation Sampling*--After bird surveys were completed, we estimated 1) vegetation volume, 2) average height of large riparian trees, and 3) width of riparian vegetation within each of our 23 study sites. We estimated vegetation volume within a 50-m radius plot surrounding each bird survey point using the point-line-intercept method (sensu Mills et al. 1991). Standing at each survey point, we first took a random compass bearing and then used a meter tape to establish a 50-m transect along this bearing. We established 5 additional 50-m transects located at 60, 120, 180, 240, and 300° from the original compass bearing. We walked along each 50-m transect and sampled vegetation at 5 vegetation sampling points. The location of each of the 5 vegetation sampling point was selected systematically within 1 of 5 distance categories along each transect (0-22.5, 22.5-31.5, 31.5-38.5, 38.5-45, 45-50 m) so that we collected samples uniformly across the 50-m radius plot. We placed one end of a 5-m graduated pole on the ground at each vegetation sampling point and used a level to ensure that the pole was positioned vertically. Using the 5-m graduated pole as a reference point, we then estimated the number of vegetation "hits" within a vertical column 0.25-m in radius centered on the pole and extending straight up and above the pole (Fig. 4). A "hit" occurred when vegetation (leaves, branches, stems, etc.) intersected the space within the vertical column. We recorded "hits" of vegetation separately for each plant species and noted whether the vegetation was alive or dead/dormant (we used the percentage of vegetation that was dead or dormant as an index of riparian vegetation "health"). We placed herbaceous plant species into 1 of 2 general categories (grasses or forbs).

We divided the vertical column into 3 general height classes (understory, mid-story, and canopy) and further divided these height classes into distinct sub-intervals. From 0-2.5 m height (the understory), we divided the vertical column into 25 10-cm sub-intervals. From 2.5-5 m height (the mid-story), we divided the vertical column into 25 10-cm sub-intervals. And finally, from 5-20 m height (the canopy), we divided the vertical column into 15 1-m sub-intervals. Although we recorded vegetation hits >20 m, we did not include these data in subsequent analyses because only a tiny fraction of vegetation "hits" (e.g., 0.1% of 86,568 total "hits" recorded in 2006) were

Figure 4. Detail of map showing a portion of the bird survey route at the Upper Hot Springs study site (red dots represent survey points #7-15 and green stippling indicates area <50 m of these survey points) at The Nature Conservancy's Muleshoe Ranch Preserve, Arizona. The light blue dot indicates a standing pool of water and the dark blue lines indicate segments of flowing water that were present on 3 May 2006.



>20 m in height. For each of the 3 height classes, we calculated the average % relative volume of vegetation (henceforth "vegetation volume") within 50 m of each bird survey point at each site using the following equation: h/xp; where h = total number of vegetation "hits" summed in each height class at each sampling point, x = the number of height intervals within each height class at each sampling point ($n$ = 25, 25, and 15, respectively), and p = the total number of sampling points ($n$ = 30) along the 6 transects at each bird survey point. To examine issues of vegetation health, we calculated the percentage of dead or dormant vegetation within 50 m of each bird survey point as 100 x (dead or dormant vegetation volume/total vegetation volume). We estimated vegetation volume for each study site by averaging total vegetation volume estimates across all bird survey points at each study site.

At each bird survey point, we estimated the height of large riparian trees using a modified version of the point-center-quarter method (Bookhout 1996). Using a meter tape, we measured the distance from the survey point to the center of the trunk of the nearest tree >40 cm Diameter at Breast Height (DBH) in each of 4 quadrants surrounding the survey point. We searched as far as 100-m from the survey point to locate a tree >40 cm DBH in each quadrant. Occasionally, no tree >40 cm was found in 1 (or more) of the 4 quadrants. If this happened, we located the next closest tree >40 cm in another quadrant and collected data from that tree. For each tree >40 cm DBH, we estimated its height with the aid of a clinometer.

Finally, we mapped the width of riparian vegetation along the stream channel within each study site by using a GPS receiver to collect UTM coordinates while walking the edge of riparian woodlands. We mapped the edges of both cottonwood-willow/mixed-broadleaf forest and mesquite/mesquite-hackberry woodlands out to 300 m on either side of the stream channel. We imported the UTM coordinates into a GIS and used the GIS to measure the approximate width of riparian vegetation (cottonwood-willow/mixed-broadleaf forest and cottonwood-willow/mixed-broadleaf forest plus mesquite/mesquite-hackberry woodlands) at each survey point. Some sites (e.g., Lower Sabino Creek) were bounded by private property or otherwise inaccessible and we were unable to map the extent of mesquite/mesquite-hackberry woodlands from the ground. Thus, we viewed aerial photographs using Google Earth (Version 3.0.0762 software, Google, Inc. 2005) to estimate the width of riparian woodlands at these study sites.

*Nest Monitoring*--From April to July in 2006 and 2007, we located and monitored nests of all riparian and upland breeding bird species in an area approximately 150 m wide (centered on the stream channel) at a subset of our study sites. Although we collected data on nests of all species, we focused our efforts on collecting data on nests of Bell's Vireos because of the relative ease in finding and monitoring nests of this species in southwestern riparian woodlands (Powell 2004). In 2007, we selected the Posta Quemada and Upper Cienega study sites to represent "dry" sites and the Cienega Creek and Rincon Creek study sites to represent "wet" sites (note that Rincon Creek was a "dry" study site during nest monitoring in 2006). We spent equal time and effort nest searching at each study site to reduce bias. We monitored nests every 2-3 days until the fate (failed or fledged) was determined. We recorded the number of eggs and/or nestlings on each nest visit and we measured the length and width of eggs at each Bell's Vireo nest that we found during the incubation period.

*Arthropod sampling*--Using sticky traps, we sampled arthropods at each bird survey point at a subset of 6 of our study sites in early June 2006 and a subset of 5 of our study sites in early June 2007 . Based on the presence of surface water at the 6 study sites in early June 2006, we classified Las Cienegas, Posta Quemada, and Rincon Creek as "dry" study sites and Aravaipa Creek, Cienega Creek, and Tumacacori as "wet" study sites. Based on the presence of surface water at the 5 study sites in early June 2007, we classified Dudleyville East and Upper Cienega as "dry" study sites and Dudleyville West, Sonoita Creek, and Rincon Creek as "wet" study sites. We sampled Rincon Creek in both 2006 and 2007 because of the dramatic increase in surface water observed at this study site from one year to the next. We sampled arthropods in early June because this is the peak of the breeding season for many riparian birds in the region (Corman and Wise-Gervais 2005). Each sticky trap consisted of a 20 x 28-cm transparency smeared with a layer of tanglefoot (Tanglefoot, Inc.). We attached each sticky trap to a 20 x 28 cm board and suspended these boards using string from a branch approximately 1 m above the ground at each survey point. We anchored the sticky traps to the ground to prevent them from blowing in the wind. We collected sticky traps after 4 days and brought them back to a lab at the University of Arizona.

Using a dissecting microscope, we identified all arthropods to taxonomic order and measured the length of each arthropod to the nearest mm. We used length-mass relationships derived for riparian arthropods (Sabo et al. 2000) to estimate dry biomass (mg) for the following arthropod orders: *Araneae* (spiders), *Coleoptera* (beetles), *Diptera* (flies), *Ephemeroptera* (mayflies), *Homoptera* (true bugs), *Hemiptera* (true bugs), *Hymenoptera* (bees, wasps, and ants), *Odonata* (dragonflies and damselflies), *Orthoptera* (grasshoppers and crickets), and *Trichoptera* (caddisflies). We used a length-mass relationship derived for terrestrial arthropods to estimate dry biomass (mg) for a composite group of the remaining orders (including unidentified arthropods; Rogers et al. 1976). We calculated average total dry biomass and average dry biomass per order across survey points at the study sites at which we trapped aerial arthropods.

*The Floods of 2006*--Southeastern Arizona experienced one of the wettest monsoons on record during July and August 2006. Heavy rains were prevalent across our study area and flash floods occurred at several of our study sites. The riparian woodlands at the Aravaipa Creek study site were hit especially hard by severe flash floods and many large cottonwood and willow trees were uprooted as a result. Several of our other study sites experienced flash floods that removed or altered understory (<2.5 m) vegetation primarily. Due to logistical constraints, we were forced to measure vegetation variables at our study sites after the floodwaters had subsided. Consequently, all of our vegetation data from Aravaipa Creek and much of the understory vegetation data that we collected at other study sites were compromised to some extent.

## DATA ANALYSIS

*Influence of Surface Water and Vegetation Health on Riparian Birds*-- We took 2 approaches to analyzing our data. First, we conducted a spatial analysis of the data from the 23 replicate study sites for which we collected at least one year's worth of data in either 2006 or 2007. We used multiple linear regression to determine the relative effects of vegetation volume, health of riparian vegetation, width of riparian vegetation, amount of surface water, etc. on bird species richness and abundance across the spatial replicates. Second, we conducted a temporal analysis of data from our 10 study sites for which we collected data each year in 2006 and 2007. We used linear regression to examine the relationship between the percent change in surface water and the change in bird relative abundance at the 10 study sites from one year to the next. For both analytical approaches, we limited our analyses to include birds detected aurally and/or visually within 50 m of each survey point and we excluded data of bird detected as flyovers. We also limited our analyses to the 38 species for which we detected a total of ≥50 individuals during replicate surveys in 2006 or 2007. For species richness analyses, we used total species richness and species richness for a subset of 27 "riparian-obligate" species found within our study area (Hunter et al. 1987, USGS Northern Prairie Research Center 2006). Before running analyses, we examined distributions of both our response and explanatory variables to check assumptions of normality and applied transformations (square root + 1, *ln* + 1, or *Log*10 +1) where necessary.

For the spatial analysis, we used factor analysis to reduce the large set of explanatory vegetation variables ($n$ = 16) to a smaller set of uncorrelated factors for use in subsequent multiple linear regression analyses. These 16 explanatory vegetation variables were: volume of all live vegetation in the understory, mid-story, and canopy; volume of all dead vegetation in the understory, mid-story, and canopy; volume of live Freemont cottonwood in the mid-story and canopy; volume of live Goodding willow in the mid-story and canopy; volume of live velvet mesquite in the understory, mid-story, and canopy; volume of live forbs in the understory; volume of live grass in the understory; and canopy height (Freemont cottonwood, Goodding willow, and velvet mesquite were the dominant riparian trees within our study sites). Using a varimax rotation, the factor analysis produced 5 factors with Eigenvalues >1. We identified these 5 factors based on the strength of their respective factor weights: Factor 1) volume of live vegetation in understory and mid-story; Factor 2) canopy height/volume of live Freemont cottonwood in canopy; Factor 3) volume of dead vegetation in understory, mid-story, and canopy; Factor 4) volume of live velvet mesquite in mid-story and canopy; and Factor 5) volume of live grass in understory. The reduced sets of factors retained 85% of the variability from the 16 original vegetation variables.

We used multiple linear regression to model relative abundance (total and by species) and species richness of birds in relation to the following explanatory variables: the 5 vegetation factors (see above), average surface area of water ($m^2$), year, average width of cottonwood-willow/mixed-broadleaf riparian vegetation at each study site, and stream size (1 = stream orders of 4, 5, or 6, and 2 = stream order >6 [e.g., San Pedro and Santa Cruz Rivers]). We used a stepwise procedure to fit candidate models by entering variables at each step (using $P \leq 0.20$ for variable inclusion and $P \leq 0.25$ for variable retention; Hosmer and Lemeshow 2000). Because we sampled vegetation after the 2006 floods (but started collecting bird data before the 2006

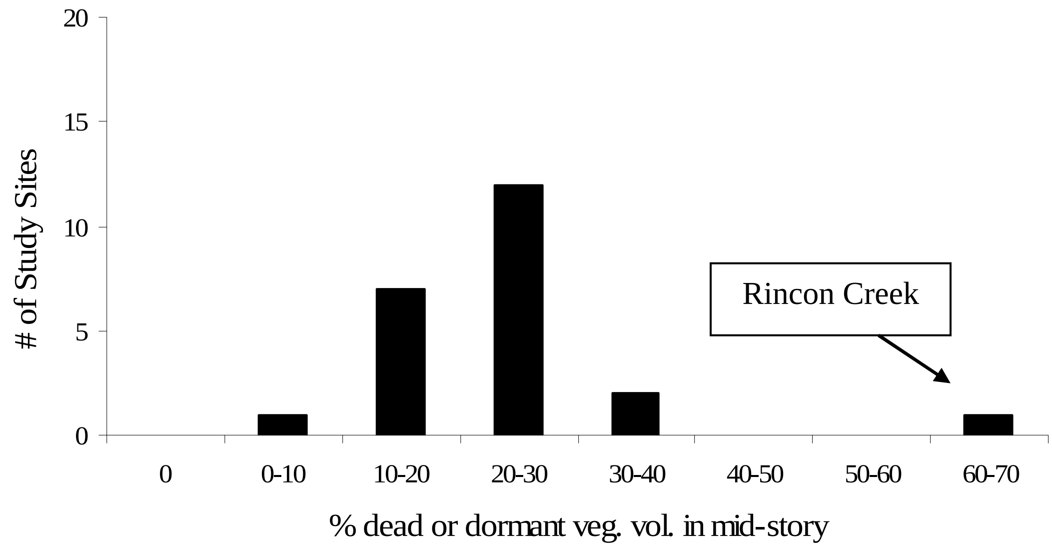
floods), we excluded data from the Aravaipa Creek study site from analyses because of the extensive flood damage to the riparian woodland at this study site. The study site at Rincon Creek had substantially more dead vegetation than any other study site and was thus an outlier in our data set (Figs. 5a-5b). Thus, we ran our spatial analysis both with and without data from the Rincon Creek study site.

*Nest Monitoring*--We calculated egg volumes using the following equation from Hoyt (1979): (egg length x (egg width x egg width)) x 0.51. We used independent samples *t*-tests to compare average clutch sizes and egg volumes for Bell's vireo at our 2 "wet" versus our 2 "dry" study sites (because we found no Bell's vireo nests at Rincon Creek in 2007, we effectively had only 1 "wet" study site in 2007).

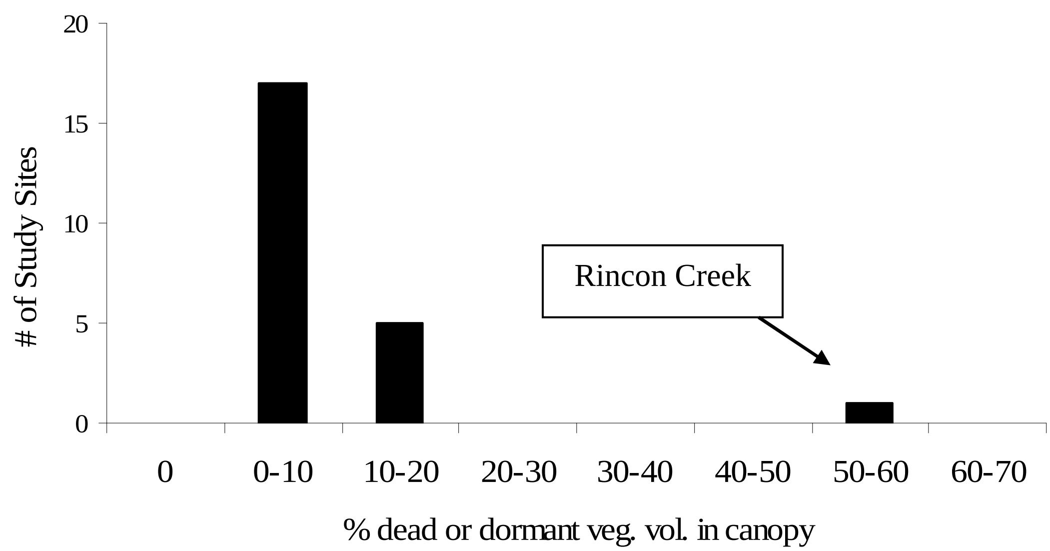
*Arthropod sampling*-- We used an independent samples one-tailed *t*-test to test the hypothesis that arthropod biomass was greater at the 5 "wet" sites compared to the 5 "dry" sites. We used a paired *t*-test to test the hypothesis that arthropod biomass was greater in 2007 (a "wet" year) compared to 2006 (a "dry" year) at 10 bird survey points at the Rincon Creek study site. For both analyses, we used a one-tailed *t*-test because of the assumption that the presence of surface water increases the abundance of arthropods within riparian woodlands. Before running analyses, we eliminated arthropods that weighed >20 mg (mostly cicadas [*Cicadidae*]) because these individuals were outliers within the data set.

Figures 5a-5b. The percentage of vegetation that was dead or dormant in A) the mid-story (2.5-5 m) or B) the canopy (5-20 m) at 23 study sites in riparian woodlands of southeastern Arizona. The Rincon Creek study site, an outlier in our data set, is indicated in both plots. We sampled vegetation once (in 2006 or 2007) at most study sites. However, we sampled vegetation twice (in 2006 and 2007) at the Rincon Creek study site. Here we show only 2006 data for the Rincon Creek study site.

A)




B)



## RESULTS

*Surface Water*-- Following a winter with above-average precipitation, surface area ($m^2$) of flowing and standing pools of water <50 m from each bird survey point increased by an average of 32% from 2006 to 2007 at the 10 study sites that we sampled in both years. Some study sites that were dry in 2006, such as Rincon Creek and Lower Las Cienegas, had flowing or standing pools of water for all or part of the bird breeding season in 2007. During the 2007 bird breeding season, surface area ($m^2$) of flowing and standing pools of water <50 m from each bird survey point decreased 53% across our 16 study sites, from an average of 279 $m^2$ in April to an average of 130 $m^2$ in June (Table 2).

*Bird Surveys*--During 4 replicate bird surveys at each of our 16 study sites in 2007, we detected a total of 13,970 individuals of 128 species (83 breeding and 49 non-breeding) that were <50 m from survey points along our riparian bird survey routes. The species that we detected most frequently were Yellow Warbler (*n* = 1,603), Yellow-breasted Chat (*n* = 852), Bewick's Wren (*n* = 811), Lesser Goldfinch (*n* = 730), Bell's Vireo (*n* = 704), Lucy's Warbler (*n* = 688), Abert's Towhee (*n* = 680), Summer Tanager (*n* = 587), Song Sparrow (*n* = 543), White-winged Dove (*n* = 527), Gila Woodpecker (*n* = 480), House Finch (*n* = 478), Brown-crested Flycatcher (*n* = 317), Northern Cardinal (*n* = 307), Mourning Dove (*n* = 269), Vermillion Flycatcher (*n* = 263), Ash-throated Flycatcher (*n* =226), Ladder-backed Woodpecker (*n* = 214), Common Yellowthroat (*n* = 187), Verdin (*n* = 180), and Brown-headed Cowbird (*n* = 179). Of the 3 bird species that are considered Arizona Partners in Flight priority species of conservation concern (Latta et al. 1999), we detected numerous Lucy's Warblers (see above), 19 Southwestern Willow Flycatchers, and 8 Western Yellow-billed Cuckoos during bird surveys in 2007.

*Influence of Surface Water and Vegetation Health on Riparian Birds (Spatial Analysis)*--Results from our stepwise multiple linear regression analyses revealed the following associations between bird parameters and surface water and/or vegetation health across the 21 study sites sampled in either 2006 or 2007. At the community level, we detected a positive association between total bird relative abundance and the presence and extent of surface water ≤50 m from bird survey points (Table 3). At the species level, we detected positive associations between the presence and extent of surface water ≤50 m from bird survey points and relative abundance of 2 species of birds: Black Phoebe and White-winged Dove (Table 4). We detected negative associations between the percentage of dead or dormant vegetation ≤50 m from bird survey points and the relative abundance of 3 species: Vermillion Flycatcher, Common-Yellowthroat, and House Finch (Table 4). We detected positive associations between the percentage of dead or dormant vegetation ≤50 m from bird survey points and the relative abundance of 3 species: Bewick's Wren, Lucy's Warbler, and Ladder-backed Woodpecker (Table 4). We found that results were consistent for most bird parameters whether we included or excluded data from the Rincon Creek study site (an outlier in our data set; see methods) from our analyses. Adjusted $R^2$ values for models were 0.62 for total bird relative abundance, 0.59 for White-winged Dove, 0.83 for Vermillion Flycatcher, 0.83 for Common Yellowthroat, and 0.62 for Bewick's Wren suggesting that the explanatory variables in the models explained the majority of the variance in the data for these species. However, adjusted $R^2$ value were lower for House Finch (0.32), Ladder-backed Warbler (0.26), Lucy's Warbler (0.39), and Black Phoebe (0.45) suggesting that additional variation in the models was attributable to unexplained variables.

Surface area ($m^2$) of flowing and standing pools of water <50 m from each bird survey point present during 4 replicate surveys from April to June 2007 at 16 study sites in southeastern Arizona. Study sites are arranged in order of decreasing average surface water.

| | Date of survey | | | | |
|---|---|---|---|---|---|
| Study Site | April | Early May | Late May | June | Average |
| Tumacacori* | 691 | 758 | 658 | 675 | 696 |
| Sonoita Creek | 544 | 614 | 635 | 672 | 616 |
| Boquillas* | 447 | 614 | 389 | 66 | 379 |
| Dudleyville West | 516 | 435 | 368 | 162 | 370 |
| Fairbanks* | 466 | 704 | 230 | 61 | 365 |
| St. David | 500 | 309 | 243 | 145 | 299 |
| Rincon Creek* | 323 | 299 | 133 | 108 | 216 |
| Cienega Creek* | 258 | 232 | 182 | 168 | 210 |
| Lower Sabino Creek* | 276 | 50 | 22 | 0 | 87 |
| Upper Hot Springs* | 64 | 95 | 46 | 30 | 59 |
| Cascabel | 173 | 38 | 0 | 0 | 53 |
| Lower Las Cienegas* | 139 | 22 | 0 | 0 | 40 |
| Arivaca* | 67 | 5 | 1 | 0 | 18 |
| Posta Quemada* | 2 | 0 | 0 | 0 | 1 |
| Dudleville East | 0 | 0 | 0 | 0 | 0 |
| Upper Cienega | 0 | 0 | 0 | 0 | 0 |
| Average | 279 | 261 | 182 | 130 | 213 |

* Sites sampled in 2006 and 2007

Table 3. Final models for community-level bird parameters (species richness and total relative abundance) generated from stepwise multiple linear regression using data collected from April-September 2006 and 2007 at 21 study sites (Aravaipa and Rincon Creek study sites were excluded from analyses; see methods) located in riparian woodlands of southeastern Arizona.

| Variables selected in final models | *b* | SE | Beta | *t* | *P* |
|---|---|---|---|---|---|
| Species richness (total) | | | | | |
| Constant | 67.800 | 4.655 | - | 14.6 | <0.001 |
| Year | -8.733 | 3.416 | -0.506 | -2.6 | 0.019 |
| | | | | | |
| Species Richness - Riparian Obligate Species | | | | | |
| Constant | 19.387 | 1.180 | - | 16.4 | <0.001 |
| Factor 2 (canopy height/volume of live POPFRE in canopy) | 1.350 | 0.400 | 0.624 | 3.4 | 0.004 |
| Factor 5 (volume of live grass in understory) | 0.931 | 0.360 | 0.438 | 2.6 | 0.020 |
| Factor 1 (volume of live vegetation. in understory and mid-story) | 0.968 | 0.426 | 0.425 | 2.3 | 0.037 |
| Year | -1.557 | 0.902 | -0.339 | -1.7 | 0.103 |
| | | | | | |
| Total relative abundance | | | | | |
| Constant | 19.558 | 2.555 | - | 7.654 | <0.001 |
| Stream size | -4.019 | 1.259 | -0.573 | -3.191 | 0.006 |
| Factor 4 (volume of live Velvet Mesquite in mid-story and canopy) | 3.409 | 0.666 | 0.978 | 5.120 | <0.001 |
| Surface water[1] | 2.271 | 0.717 | 0.609 | 3.170 | 0.006 |
| Year | -1.778 | 1.143 | -0.231 | -1.555 | 0.139 |

[1] *Log*10 +1 transformation applied to variable.

Table 4. Final models for 8 species of riparian birds that were associated with either the presence and extent of surface water ($m^2$) or the percentage of dead or dormant vegetation ≤50 m from each bird survey point. Models were generated from stepwise multiple linear regression using data collected from April-September 2006 and 2007 at 21 study sites (Aravaipa and Rincon Creek study sites were excluded from analyses; see methods) located in riparian woodlands of southeastern Arizona.

| Variables selected in final models | *b* | SE | Beta | *t* | *P* |
|---|---|---|---|---|---|
| <u>White-winged Dove</u> | | | | | |
| Constant | 1.182 | 0.070 | - | 17.0 | <0.001 |
| Stream size | -0.236 | 0.055 | -0.819 | -4.3 | 0.001 |
| Factor 4 (volume of live Velvet Mesquite in mid-story and canopy) | 0.138 | 0.031 | 0.967 | 4.501 | 0.001 |
| Surface water[1] | 0.110 | 0.033 | 0.719 | 3.4 | 0.004 |
| Factor 2 (canopy height/volume of live Freemont Cottonwood in canopy) | -0.076 | 0.026 | -0.514 | -2.9 | 0.010 |
| <u>Ladder-backed Woodpecker</u> | | | | | |
| Constant | 1.098 | 0.010 | - | 112.0 | <0.001 |
| Factor 3 (volume of dead vegetation in understory, mid-story, and canopy) | 0.028 | 0.013 | 0.450 | 2.3 | 0.036 |
| Factor 1 (volume of live vegetation in understory and mid-story) | 0.015 | 0.011 | 0.269 | 1.4 | 0.192 |
| <u>Black Phoebe</u> | | | | | |
| Constant | -0.072 | 0.029 | - | -2.5 | 0.024 |
| Surface water[1] | 0.066 | 0.016 | 0.925 | 4.3 | 0.001 |
| Factor 4 (volume of live Velvet Mesquite in mid-story and canopy) | 0.041 | 0.015 | 0.607 | 2.8 | 0.012 |
| <u>Vermillion Flycatcher</u> | | | | | |
| Constant | 0.603 | 0.072 | - | 8.4 | <0.001 |
| Factor 1 (volume of live vegetation in understory and mid-story) | -0.146 | 0.043 | -0.347 | -3.4 | 0.004 |
| Stream size | -0.526 | 0.114 | -0.677 | -4.6 | 0.001 |
| Factor 5 (volume of live grass in understory) | 0.113 | 0.040 | 0.287 | 2.8 | 0.013 |
| Factor 4 (volume of live Velvet Mesquite in mid-story and canopy) | 0.182 | 0.050 | 0.471 | 3.6 | 0.003 |
| Factor 3 (volume of dead vegetation in understory, mid-story, and canopy) | -0.215 | 0.057 | -0.438 | -3.8 | 0.002 |
| Factor 2 (canopy height/volume of live Freemont Cottonwood in canopy) | 0.097 | 0.043 | 0.242 | 2.3 | 0.040 |

Table 4 cont.

| Variables selected in final models | *b* | SE | Beta | *t* | *P* |
|---|---|---|---|---|---|
| Bewick's Wren | | | | | |
| Constant | 3.329 | 0.673 | - | 5.0 | <0.001 |
| Factor 2 (canopy height/volume of live Freemont Cottonwood in canopy) | 0.222 | 0.074 | 0.495 | 3.0 | 0.011 |
| Factor 3 (volume of dead vegetation in understory, mid-story, and canopy) | -0.339 | 0.176 | -0.356 | -1.9 | 0.077 |
| Factor 4 (volume of live Velvet Mesquite in mid-story and canopy) | 0.157 | 0.095 | 0.287 | 1.6 | 0.123 |
| Stream size | 0.169 | 0.085 | 0.391 | 2.0 | 0.068 |
| Width riparian area (m)[2] | -0.595 | 0.231 | -0.685 | -2.6 | 0.023 |
| Factor 5 (volume of live grass in understory) | -0.329 | 0.150 | -0.627 | -2.2 | 0.047 |
| Lucy's Warbler | | | | | |
| Constant | 1.847 | 0.328 | - | 5.6 | <0.001 |
| Factor 4 (volume of live Velvet Mesquite in mid-story and canopy) | 0.201 | 0.100 | 0.371 | 2.0 | 0.060 |
| Year | -0.603 | 0.237 | -0.505 | -2.5 | 0.021 |
| Factor 3 (volume of dead vegetation in understory, mid-story, and canopy) | 0.240 | 0.137 | 0.349 | 1.8 | 0.096 |
| Common Yellowthroat | | | | | |
| Constant | -0.216 | 0.322 | - | -0.7 | 0.514 |
| Stream size | -0.315 | 0.109 | -0.493 | -3.0 | 0.012 |
| Factor 3 (volume of dead vegetation in understory, mid-story, and canopy) | -0.195 | 0.045 | -0.483 | -4.3 | 0.001 |
| Factor 2 (canopy height/volume of live Freemont Cottonwood in canopy) | 0.098 | 0.036 | 0.297 | 2.7 | 0.018 |
| Factor 5 (volume of live grass in understory) | 0.135 | 0.037 | 0.419 | 3.6 | 0.003 |
| Width riparian area (m)[2] | 0.143 | 0.064 | 0.371 | 2.2 | 0.041 |
| Factor 4 (volume of live Velvet Mesquite in mid-story and canopy) | 0.073 | 0.041 | 0.229 | 1.8 | 0.099 |
| House Finch | | | | | |
| Constant | 1.296 | 0.346 | - | 3.8 | 0.002 |
| Year | -0.397 | 0.249 | -0.332 | -1.6 | 0.130 |
| Factor 4 (volume of live Velvet Mesquite in mid-story and canopy) | 0.185 | 0.105 | 0.341 | 1.8 | 0.097 |
| Factor 3 (volume of dead vegetation in understory, mid-story, and canopy) | -0.226 | 0.144 | -0.328 | -1.6 | 0.135 |

[1] *Log10* + 1 transformation applied to variable.
[2] *Ln* + 1 transformation applied to variable.

*Influence of Surface Water on Riparian Birds (Temporal Analysis)*--Results from our linear regression analyses revealed the following relationships between the percent change in surface water ≤50 m from bird survey points and the change in bird relative abundance at 10 study sites that were sampled in both 2006 and 2007 (Table 5). We found that relative abundances of Black Phoebe, Northern Beardless-tyrannulet, and Vermillion Flycatcher were positively associated with increasing surface water ≤50 m from bird survey points. In addition, we found that total relative abundance of birds was positively associated with increasing surface water ≤50 m from bird survey points, although this association was only marginally significant ($P = 0.145$).

*Arthropod Sampling*--Using sticky traps, we captured arthropods representing 18 Orders at our 10 study sites (5 "wet" and 5 "dry"; Table 5). In terms of total dry biomass, 37% of the dry biomass was attributable to Hymenoptera, 18% to Diptera, 11% to Homoptera or Hemiptera, 11% to Coleoptera, and the remaining 23% to other Orders. Total dry biomass of arthropods was 89% greater at "wet" vs. "dry" study sites. In addition, dry biomass was greater for Diptera (155%) and Orthoptera (317%) at "wet" vs. "dry" study sites. Although most trends were not statistically significant, dry biomass for 17 of 18 arthropod Orders was greater at "wet" vs. "dry" study sites (only dry biomass of Neuroptera was greater at "dry" sites). In addition, 3 arthropod Orders in which all species have an aquatic life stage (*Ephemeroptera*, *Odonata*, and *Trichoptera*) were only captured on sticky traps at "wet" study sites.

When we compared arthropods captured at our Rincon Creek study site in 2006 (a "dry" year) and 2007 (a "wet" year), we found that total dry biomass of arthropods increased 171% at Rincon Creek from one year to the next (Table 6). In addition, dry biomass increased for Coleoptera (369%), Diptera (268%), and Hemiptera (4,300%) from 2006 to 2007. Only dry biomass of Thysanoptera decreased (63%) from 2006 to 2007. We captured individuals of 2 arthropod Orders in which all species have an aquatic life stage (*Ephemeroptera* and *Trichoptera*) at Rincon Creek in 2007 but not in 2006.

*Nest Monitoring*--From April-July 2007, we located a total of 382 nests of 46 species at 4 study sites (Cienega Creek, Posta Quemada, Upper Cienega Creek, and Rincon Creek). We found 116 nests of 31 species at the Cienega Creek study site, 101 nests of 30 species (including 1 Yellow-billed Cuckoo nest) at the Upper Cienega Creek study site, 108 nests of 26 species at the Posta Quemada study site, and 59 nests of 23 species at Rincon Creek study site (Table 8). We found a total of 100 Bell's Vireo nests at 3 of our 4 study sites (Fig. 6; Rincon Creek had no breeding Bell's Vireos in 2007). We were unable to detect a difference in Bell's vireo clutch size between our "wet" sites ($\bar{x}$ = 3.47 eggs, $n = 15$) versus our "dry" sites ($\bar{x}$ = 3.35 Eggs, $n = 20$; $t = 1.7$, $P = 0.579$). We were also unable to detect a difference in Bell's vireo egg volume between our "wet" sites ($\bar{x}$ = 1,420 $mm^3$ eggs, $n = 19$) versus our "dry" sites ($\bar{x}$ = 1,404 $mm^3$, $n = 28$; $t = 1.7$, $P = 0.753$).

Table 5. Results from linear regression to examine the relationship between the percent change in surface water and the change in bird relative abundance between 2006 and 2007 at 10 study sites located in riparian woodlands of southeastern Arizona.

| Models | *b* | SE | Beta | *t* | *P* |
|---|---|---|---|---|---|
| Total relative abundance | | | | | |
| Constant | -3.523 | 1.445 | - | -2.4 | 0.041 |
| Percent change in surface water | 0.044 | 0.027 | 0.495 | 1.6 | 0.145 |
| Black Phoebe | | | | | |
| Constant | -0.027 | 0.015 | - | -1.857 | 0.100 |
| Percent change in surface water | 0.000 | 0.000 | 0.537 | 1.800 | 0.110 |
| Northern Beardless-tyrannulet | | | | | |
| Constant | -0.061 | 0.025 | - | -2.443 | 0.040 |
| Percent change in surface water | 0.001 | 0.000 | 0.554 | 1.884 | 0.096 |
| Vermillion Flycatcher | | | | | |
| Constant | 0.015 | 0.060 | - | 0.252 | 0.808 |
| Percent change in surface water | 0.003 | 0.001 | 0.636 | 2.329 | 0.048 |
| Ash-throated Flycatcher | | | | | |
| Constant | 0.307 | 0.074 | - | 4.139 | 0.003 |
| Percent change in surface water | -0.004 | 0.001 | -0.737 | -3.087 | 0.015 |
| Ladder-backed Woodpecker | | | | | |
| Constant | 0.154 | 0.072 | - | 2.149 | 0.064 |
| Percent change in surface water | -0.002 | 0.001 | -0.508 | -1.666 | 0.134 |

Table 6. Average dry biomass per trap (mg; mean ± SE) of arthropods within 18 Orders captured using sticky traps placed at approximately 1-m height at survey points located within 5 “wet” study sites and 5 “dry” study sites in riparian woodlands of southeastern Arizona during a 4-day sampling period in early June (2006 and 2007 data combined).

| | “Wet” Sites | | “Dry” Sites | | | | |
|---|---|---|---|---|---|---|---|
| Order | $\bar{x}$ | SE | $\bar{x}$ | SE | Mean Difference | $t$ | $P_{one\text{-}tailed}$ |
| *Acari* | 0.03 | 0.01 | 0.02 | 0.01 | 0.01 | 0.7 | 0.254 |
| *Araneae* | 1.40 | 0.22 | 1.25 | 0.17 | 0.15 | 0.5 | 0.302 |
| *Colembola* | 0.00 | 0.00 | 0.00 | 0.00 | 0 | -0.3 | 0.371 |
| *Coleoptera* | 21.39 | 9.32 | 3.17 | 1.18 | 18.22 | 1.0 | 0.180 |
| *Diptera* | 27.82 | 7.12 | 11.91 | 3.08 | 15.91 | 2.0 | 0.046 |
| *Ephemeroptera* | 0.80 | 0.53 | 0 | 0 | 0.80 | 1.5 | 0.100 |
| *Hemiptera* | 4.63 | 2.04 | 1.49 | 0.44 | 3.14 | 1.5 | 0.101 |
| *Homoptera* | 14.32 | 6.73 | 4.19 | 1.37 | 10.13 | 1.5 | 0.105 |
| *Hymenoptera* | 46.45 | 15.78 | 33.45 | 9.34 | 13 | 0.7 | 0.252 |
| *Isoptera* | 0.20 | 0.14 | 0.00 | 0.00 | 0.20 | 1.5 | 0.107 |
| *Lepidoptera* | 3.26 | 1.00 | 2.17 | 0.80 | 1.09 | 0.8 | 0.212 |
| *Mecoptera* | 0.13 | 0.08 | 0.13 | 0.04 | 0 | 0.0 | 0.487 |
| *Neuroptera* | 0.18 | 0.17 | 0.68 | 0.42 | -0.50 | -1.1 | 0.157 |
| *Odonata* | 6.77 | 6.77 | 0 | 0 | 6.77 | 1.0 | 0.187 |
| *Orthoptera* | 3.63 | 1.86 | 0.63 | 0.63 | 3.00 | 1.5 | 0.095 |
| *Psocoptera* | 0.01 | 0.01 | 0.0 | 0.0 | 0.01 | 0.7 | 0.273 |
| *Thysanoptera* | 9.66 | 5.25 | 5.55 | 2.93 | 4.11 | 0.7 | 0.264 |
| *Trichoptera* | 0.33 | 0.24 | 0 | 0 | 0.33 | 1.4 | 0.122 |
| Total | 141.61 | 36.83 | 73.68 | 14.61 | 67.93 | 4.0 | 0.073 |

Table 7. Average dry biomass per trap (mg; mean ± SE) of arthropods within 14 Orders captured using sticky traps placed at approximately 1-m height at 10 bird survey points at Rincon Creek study site in early June 2006 (a "dry" year) and early June 2007(a "wet" year).

| | 2006 | | 2007 | | | | |
|---|---|---|---|---|---|---|---|
| Order | $\bar{x}$ | SE | $\bar{x}$ | SE | Mean Difference | $t$ | $P_{one\text{-}tailed}$ |
| *Acari* | 0.04 | 0.01 | 0.04 | 0.02 | 0.00 | 0.4 | 0.331 |
| *Araneae* | 1.07 | 1.03 | 0.33 | 0.69 | -0.74 | -0.7 | 0.250 |
| *Coleoptera* | 3.54 | 0.93 | 16.60 | 2.98 | 13.06 | 4.4 | 0.001 |
| *Diptera* | 9.51 | 1.23 | 34.96 | 4.52 | 25.45 | 6.1 | <0.005 |
| *Ephemeroptera* | 0.00 | 0.00 | 0.26 | 0.19 | 0.26 | 1.4 | 0.098 |
| *Hemiptera* | 0.01 | 0.01 | 0.44 | 0.18 | 0.43 | 2.4 | 0.012 |
| *Homoptera* | 0.92 | 0.56 | 1.02 | 0.50 | 0.10 | 0.3 | 0.370 |
| *Hymenoptera* | 7.97 | 2.64 | 11.78 | 3.40 | 3.81 | 0.9 | 0.194 |
| *Lepidoptera* | 0.15 | 0.15 | 0.37 | 0.32 | 0.22 | 0.6 | 0.286 |
| *Mecoptera* | 0.25 | 0.18 | 0.19 | 0.02 | -0.06 | -0.2 | 0.417 |
| *Neuroptera* | 0.00 | 0.00 | 0.50 | 0.50 | 0.50 | 1.0 | 0.172 |
| *Strepsiptera* | 0.02 | 0.02 | 0.00 | 0.00 | -0.02 | -1.0 | 0.172 |
| *Thysanoptera* | 1.55 | 0.30 | 0.95 | 0.15 | -0.60 | -2.1 | 0.034 |
| *Trichoptera* | 0.00 | 0.00 | 0.08 | 0.06 | 0.08 | 1.4 | 0.102 |
| Total | 24.82 | 2.31 | 67.37 | 6.70 | 42.55 | 6.3 | <0.005 |

Table 8. Summary nest characteristics for 369 nests of 46 species found at 4 study sites (Cienega Creek, Posta Quemada, Rincon Creek, and Upper Cienega Creek) located in riparian woodlands of southeastern Arizona, April-July 2007.

| | | Nesting substrate[1] | | | | Species of plant comprising nesting substrate[2] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | *n* | 1st | % | 2nd | % | 1st | % | 2nd | % | 3rd | % | 4th | % |
| Abert's Towhee | 12 | BR | 100 | - | - | TAMARI | 33 | ZIZOBT | 33 | OTHER | 33 | - | - |
| Ash-throated Flycatcher | 6 | CA | 80 | MI | 20 | SALGOO | 60 | OTHER | 40 | - | - | - | - |
| Broad-billed Hummingbird | 3 | BR | 100 | - | - | CELRET | 33 | ZIZOBT | 33 | SALGOO | 33 | - | - |
| Brown-crested Flycatcher | 5 | CA | 100 | - | - | CARGIG | 80 | SALGOO | 20 | - | - | - | - |
| Black-chinned Hummingbird | 25 | BR | 100 | - | - | CELRET | 32 | FRAPEN | 28 | PROVEL | 12 | OTHER | 18 |
| Bell's Vireo | 100 | BR | 100 | - | | ZIZOBT | 17 | PROVEL | 15 | CELRET | 14 | OTHER | 54 |
| Bewick's Wren | 7 | CA | 100 | - | - | SALGOO | 14 | PROVEL | 14 | JUGMAJ | 14 | PROVEL | 56 |
| Blue Grosbeak | 4 | BR | 100 | - | - | CELRET | 50 | ZIZOBT | 25 | TAMARI | 25 | - | - |
| Black Phoebe | 2 | BD | 100 | - | - | - | - | - | - | - | - | - | - |
| Black-throated Sparrow | 12 | BR | 93 | MI | 7 | PROVEL | 42 | ACAGRE | 17 | OTHER | 41 | - | - |
| Bullock's Oriole | 1 | BR | 100 | - | - | POPFRE | 100 | - | - | - | - | - | - |
| Cassin's Kingbird | 7 | BR | 100 | - | - | POFRE | 43 | SALGOO | 29 | OTHER | 28 | - | - |
| Canyon Towhee | 2 | BR | 100 | - | - | ACAGRE | 50 | PROVEL | 50 | - | - | - | - |
| Canyon Wren | 1 | SH | 100 | - | - | - | - | - | - | - | - | - | - |
| Curve-billed Thrasher | 1 | BR | 100 | - | - | OPUNTIA | 100 | - | - | - | - | - | - |
| Common Raven | 1 | BR | 100 | - | - | POPFRE | 100 | - | - | - | - | - | - |
| Copper's Hawk | 4 | BR | 100 | - | - | POPFRE | 75 | SALGOO | 25 | - | - | - | - |
| Costa's Hummingbird | 1 | BR | 100 | - | - | - | - | - | - | - | - | - | - |
| Gambel's Quail | 1 | GR | 100 | - | - | - | - | - | - | - | - | - | - |
| Gilded Flicker | 2 | CA | 100 | - | - | CARGIG | 100 | - | - | - | - | - | - |
| Gila Woodpecker | 3 | CA | 100 | - | - | CARGIG | 66 | PROVEL | 33 | - | - | - | - |
| Gray Hawk | 3 | BR | 100 | - | - | POPFRE | 100 | - | - | - | - | - | - |
| House Finch | 4 | BR | 75 | MI | 25 | POPFRE | 25 | FRAPEN | 25 | CELRET | 25 | PROVEL | 25 |
| House Sparrow | 1 | CA | 100 | - | - | CARGIG | 100 | - | - | - | - | - | - |
| Inca Dove | 1 | BR | 100 | - | - | SALGOO | 100 | - | - | - | - | - | - |
| Ladder-backed Woodpecker | 3 | CA | 100 | - | - | PROVEL | 33 | SALGOO | 33 | POPFRE | 33 | - | - |
| Lesser Goldfinch | 5 | BR | 100 | - | - | POPFRE | 20 | SALGOO | 20 | FRAPEN | 20 | TAMARI | 20 |
| Lucy' Warbler | 25 | CA | 76 | BF | 20 | PROVEL | 40 | ACAGRE | 16 | OTHER | 44 | - | - |
| Mourning Dove | 14 | BR | 100 | - | - | FRAPEN | 29 | PROVEL | 29 | SALGOO | 21 | - | - |
| Northern Beardless-tyrannulet | 1 | BR | 100 | - | - | FRAPEN | 100 | - | - | - | - | - | - |
| Northern Cardinal | 18 | BR | 88 | MI | 12 | CELRET | 28 | PROVEL | 22 | SALGOO | 17 | OTHER | 33 |

Table 8 cont.

| | | Nesting substrate[1] | | | | Species of plant comprising nesting substrate[2] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | *n* | 1st | % | 2nd | % | 1st | % | 2nd | % | 3rd | % | 4th | % |
| North. Rough-winged Swallow | 2 | BD | 50 | BA | 50 | - | - | - | - | - | - | - | - |
| Phainopepla | 3 | BR | 100 | - | - | FRAPEN | 100 | | | | | | |
| Purple Martin | 3 | CA | 100 | - | - | CARGIG | 100 | - | - | - | - | - | - |
| Rufous-crowned Sparrow | 1 | BR | 100 | - | - | ZIZOBT | 100 | - | - | - | - | - | - |
| Red-tailed Hawk | 2 | BR | 100 | - | - | POPFRE | 100 | - | - | - | - | - | - |
| Rufous-winged Sparrow | 9 | BR | 100 | - | - | PROVEL | 44 | ACAGRE | 11 | ZIZOBT | 11 | OTHER | 33 |
| Summer Tanager | 12 | BR | 100 | - | - | POPFRE | 33 | PROVEL | 25 | OTHER | 42 | - | - |
| Vermillion Flycatcher | 12 | BR | 100 | - | - | POPFRE | 33 | FRAPEN | 25 | SALGOO | 17 | - | - |
| Verdin | 30 | BR | 100 | - | - | ZIZOBT | 40 | CELRET | 27 | POPFRE | 7 | OTHER | 26 |
| Western Kingbird | 1 | BR | 100 | - | - | FRAPEN | 100 | - | - | - | - | - | - |
| White-Winged Dove | 10 | BR | 100 | - | - | SALGOO | 40 | FRAPEN | 30 | PROVEL | 30 | - | - |
| Yellow-breasted Chat | 12 | BR | 100 | - | - | ZIZOBT | 42 | SALGOO | 25 | FRAPEN | 17 | OTHER | 16 |
| Yellow-billed Cuckoo | 1 | BR | 100 | - | - | POPFRE | 100 | - | - | - | - | - | - |
| Yellow Warbler | 8 | BR | 100 | - | - | POPFRE | 88 | PROVEL | 12 | - | - | - | - |
| Zone-tailed Hawk | 1 | BR | 100 | - | - | POPFRE | 100 | - | - | - | - | - | - |

[1] BA = Bank; BD = bridge; BF = bark flake; BR = branch; CA = cavity; GR = ground; MI = mistletoe; SH = shed;
[2] CARGIG = saguaro cactus (Carnegiea gigantea); CELRET = (*Celtis reticulate*); FRAPEN = velvet ash (*Fraxinus pennsylvanica*); OPUNTIA = cholla cacti spp. (*Opuntia* spp.); POPFRE = Fremont cottonwood (*Populus fremontii*); PROVEL = velvet ash (*Prosopis velutina*); SALGOO = Goodding willow (*Salix gooddingii*); TAMARI = tamarisk spp. (*Tamaricaceae* spp.); ZIZOBT = graythorn (*Ziziphus obtusifolia*).

Fig. 6.  Bell’s Vireos feeding young at Cienega Creek, Arizona in 2007 (photo by B. Taubert).

## DISCUSSION

During the first year of the study (2006), we found positive associations between the presence and extent of surface water and the relative abundance of several species of riparian birds (Kirkpatrick et al. 2007). Our results also suggested that the relative abundance of several additional species of riparian birds may have been positively associated with the presence and extent of surface water (Kirkpatrick et al. 2007). However, we needed to increase our sample size of replicate study sites in order to assess whether these patterns existed or not. During the second year of the study (2007), we were able to expand the project by incorporating 6 additional replicate study sites into our study design, thus increasing the power of our spatial analysis. Moreover, we were able to conduct a temporal analysis to compare means in bird relative abundance through time as surface water conditions varied from 2006 to 2007 at a subset of 10 of our study sites. Taking this second approach to examining our data was especially useful given that the southwestern U.S. experienced an extremely dry year in 2006 followed by a year with above-average precipitation in 2007. This increase in precipitation resulted in an average increase of 32% more surface water at each of the 10 study sites in 2007 compared to 2006.

Using both of these analytical approaches, we were able to detect several positive associations between bird relative abundance and presence and extent of surface water within our study area. For example, we found that the presence and extent of surface water had a positive effect on total relative abundance of riparian birds, with this pattern being consistent in both our spatial and temporal analyses. We also found positive associations between surface water and relative abundance for 4 bird species: Black Phoebe, Vermillion Flycatcher, Northern Beardless-tyrannulet, and White-winged Dove. The Black Phoebe is a year-round resident in southern Arizona and is described as being "invariably associated with water" (Wolf 1997; p. 1) and "seldom encountered away from water sources" (Corman and Wise-Gervais 2005; p. 312). The Vermillion Flycatcher and Northern Beardless-tyrannulet are two species that are dependent on riparian vegetation in the southwestern U.S. and are often found in the vicinity of surface water (Corman and Wise-Gervais 2005; Wolf and Jones 2000). Although White-winged Doves are found breeding in a wide range of environments (Corman and Wise-Gervais 2005), previous studies indicate that White-winged Doves prefer woodlands next to oxbow lakes or other surface water in parts of their breeding range (Schwertner et al. 2002). In addition, Corman and Wise-Gervais (2005) noted that white-winged doves reach their highest nesting densities in low-elevation riparian woodlands in Arizona. In contrast, we found negative associations between the relative abundance of 2 bird species and the presence and extent of surface water across our study sites. We found that Ash-throated Flycatchers and Ladder-backed Woodpeckers were less common in riparian woodlands that had extensive surface water. Previous research has shown that the Ash-throated Flycatcher prefers dry washes to cottonwood-willow forests in Arizona (Corman and Wise Gervais 2005). The Ladder-backed Woodpecker is also known to prefer dry washes over mesic riparian woodlands (Corman and Wise-Gervais 2005).

In addition to looking for associations between our various bird parameters and surface water conditions, we also sought to identify potential ecological processes (e.g., food resources) underlying these associations. We were unable to detect a difference in average clutch size or egg volume between our "wet" and "dry" sites for Bell's vireo, our focal nest-monitoring species. However, results from our aerial arthropod sampling indicate that aerial arthropod

biomass was substantially greater at “wet” versus “dry” study sites. “Wet” study sites had on average 68 mg more dry aerial arthropod biomass per trap than “dry” study sites (an 89% difference). Although most trends were not statistically significant, dry biomass for 17 of 18 arthropod Orders was greater at “wet” vs. “dry” study sites. In addition, 3 arthropod Orders in which all species have an aquatic life stage (*Ephemeroptera*, *Odonata*, and *Trichoptera*) were only captured on traps at “wet” study sites. Similarly, we found that dry aerial arthropod biomass increased by an average of 42 mg per trap from 2006 to 2007 at the Rincon Creek study site. In addition, several arthropod orders that have aquatic life stages (e.g., *Ephemeroptera*, *Tricoptera*) that were absent from Rincon Creek in 2006 were present at this study site in 2007. The appearance of these arthropod orders at Rincon Creek during wet conditions in 2007 (but not during dry conditions in 2006) suggests that some arthropods can respond quickly to changes in surface water conditions from one year to the next.

Riparian bird species that prey heavily upon aerial arthropods likely benefit from foraging in riparian woodlands that have greater surface water because of the increased aerial arthropod biomass found in these areas. For example, Vermillion Flycatchers prey exclusively upon aerial arthropods (e.g., *Hymenoptera*, *Coleoptera*, and *Orthoptera*). Black Phoebes also feed primarily on aerial arthropods, often within a few meters of standing or flowing surface water (Wolf 1997). Indeed, we found that Black Phoebes were absent at both the Rincon Creek and Lower Las Cienegas study sites in 2006 (when there was no surface water present) but present at these 2 sites in 2007 (when there was an average of 216 $m^2$ and 40 $m^2$ of surface water $\leq$50 m from each bird survey point at Rincon Creek and Lower Las Cienegas, respectively). This increase in relative abundance of Black Phoebes suggests that this species can respond rapidly to increases in surface water and aerial arthropods from one year to the next.

Because native riparian trees are highly sensitive to changes in ground water levels in the desert southwest (Brown 1994, Ohmart 1994, Webb and Leake 2005), rapid lowering of ground water levels can kill riparian trees within a short period of time (Webb and Leake 2005) or force trees to become dormant (C. Kirkpatrick, personal observation). To examine this potential threat, we sought to determine how the health of riparian vegetation influenced avian species richness and relative abundance across our study sites. We were unable to detect any associations between the health of riparian vegetation and avian species richness or relative abundance in 2006 (Kirkpatrick et al. 2007). However, after increasing our sample size of replicate study sites in 2007, we were able to detect associations between the health of riparian vegetation and relative abundance for several bird species. For example, we found that Vermillion Flycatchers, Common Yellowthroats, and House Finches were negatively associated with the percentage of dead or dormant riparian vegetation at our study sites. In contrast, we found that Ladder-backed Woodpeckers, Lucy’s Warblers, and Bewick’s Wrens were positively associated with the percentage of dead or dormant riparian vegetation. Ladder-backed woodpeckers are known to increase in disturbed (e.g., burned) areas, perhaps in response to an increase in insect prey within dead or dying vegetation (Kirkpatrick et al. 2002). Lucy’s Warblers and Bewick’s Wrens typically nest in cavities or behind dead bark flakes (Kennedy and White 1997, Johnson et al. 1997) and may respond positively to the increased availability of nest sites (e.g., cavities, loose bark flakes) following the death of some riparian vegetation.

Results from our study provide some of the first evidence that the presence and extent of surface water and the health of riparian vegetation can influence the relative abundance of birds within riparian woodlands of the desert southwest. Ground water use in Arizona has increased rapidly during the 20th century (Webb and Leake 2005) and will continue to increase as human populations grow in the desert southwest. In light of this threat, many riparian woodlands face an uncertain future, perhaps none more so than the riparian woodland along the Upper San Pedro River. Ground water use at Fort Huachuca Military Reservation and the City of Sierra Vista has not substantially reduced ground water levels in the alluvial aquifer; however, future ground water developments in the area pose a major threat to nearby riparian woodlands along the Upper San Pedro River (Stromberg et al. 1996, Pool and Coes 1999). We believe that riparian bird communities along the Upper San Pedro River (and elsewhere in the desert southwest) are threatened in 2 ways by future ground water loss. First, should ground water levels fall to the point where surface water flows are reduced or eliminated (i.e., a “Stage 2” effect of ground water pumping; Webb and Leake 2005), populations of bird species such as Black Phoebe, Vermillion Flycatcher, Northern Beardless-tyrannulet, and White-winged Dove are likely to decline. Second, should ground water levels fall to the point that riparian vegetation is strongly affected (i.e., a “Stage 3” effect of ground water pumping; Webb and Leake 2005), populations of many other bird species, including Vermillion Flycatchers, Common Yellowthroats, and House Finches, are likely to decline. Continued drought conditions in the desert southwest are likely to compound problems associated with ground water withdrawal in the foreseeable future (Webb and Leake 2005).

Developing a sustainable water management plan is critical for Fort Huachuca and other military installations located in the southwestern U.S. If no effort is made to preserve the health of riparian woodlands in the desert southwest (including riparian woodlands on or near military installations), the potential loss of breeding, wintering, and/or migratory habitat could be substantial for many bird species, especially if ground water loss is great enough to degrade or eliminate riparian vegetation. Most riparian woodlands in the desert southwest have already been altered by human development, cattle grazing, ground water withdrawal, or surface water diversions (Ohmart 1994, Webb and Leake 2005). Thus, we need to protect the health of the remaining riparian woodland in the region given the sheer number of bird species that are dependent upon this threatened resource. Military readiness could be jeopardized if limited military resources are diverted from the military’s mission at Fort Huachuca Military Reservation (and at other military installations in the southwestern U.S.) to deal with the recovery of potentially dozens of declining populations of birds. Results from this study provide quantitative data that will allow resource managers on military lands to better predict how abundance and diversity of riparian birds will be affected by future reductions in ground and surface water levels on or near military installations in the desert southwest. This research project addresses an emerging issue that will only become more important as an expanding human population places more demands on limited water resources in the desert southwest. We plan to continue this DOD Legacy Resource Management funded project research for one more year in 2008.

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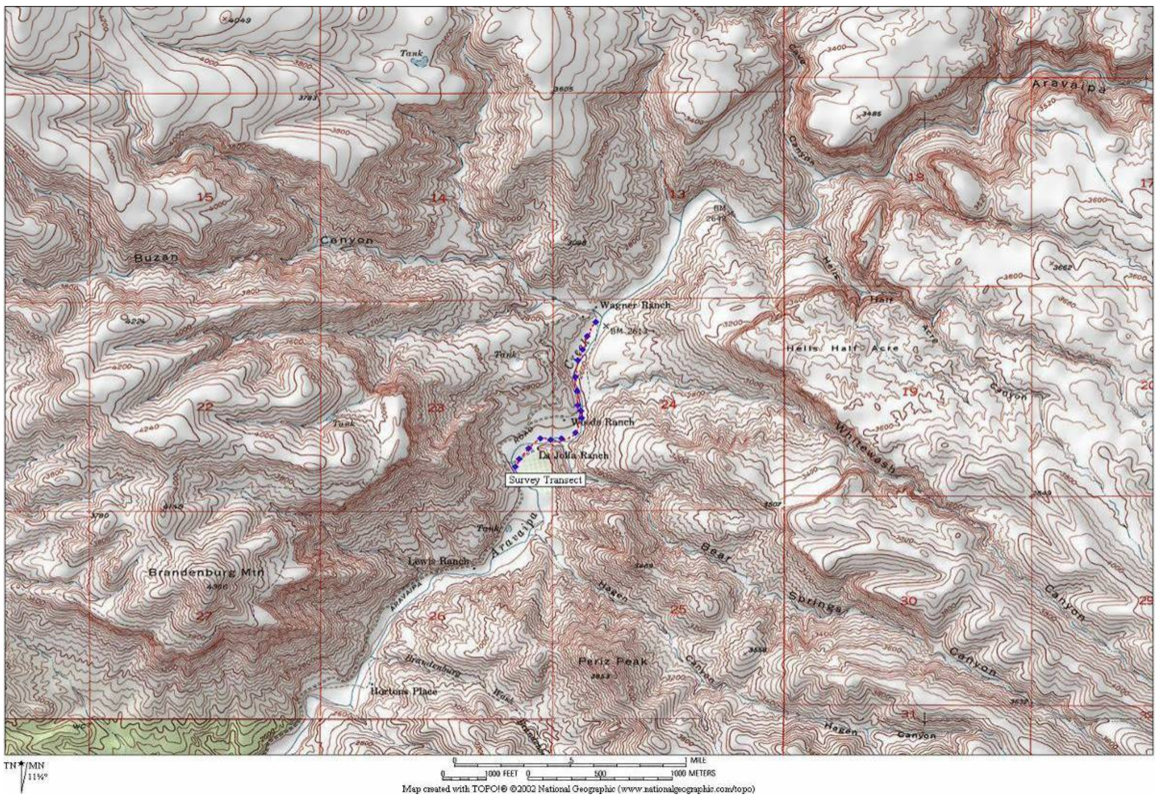
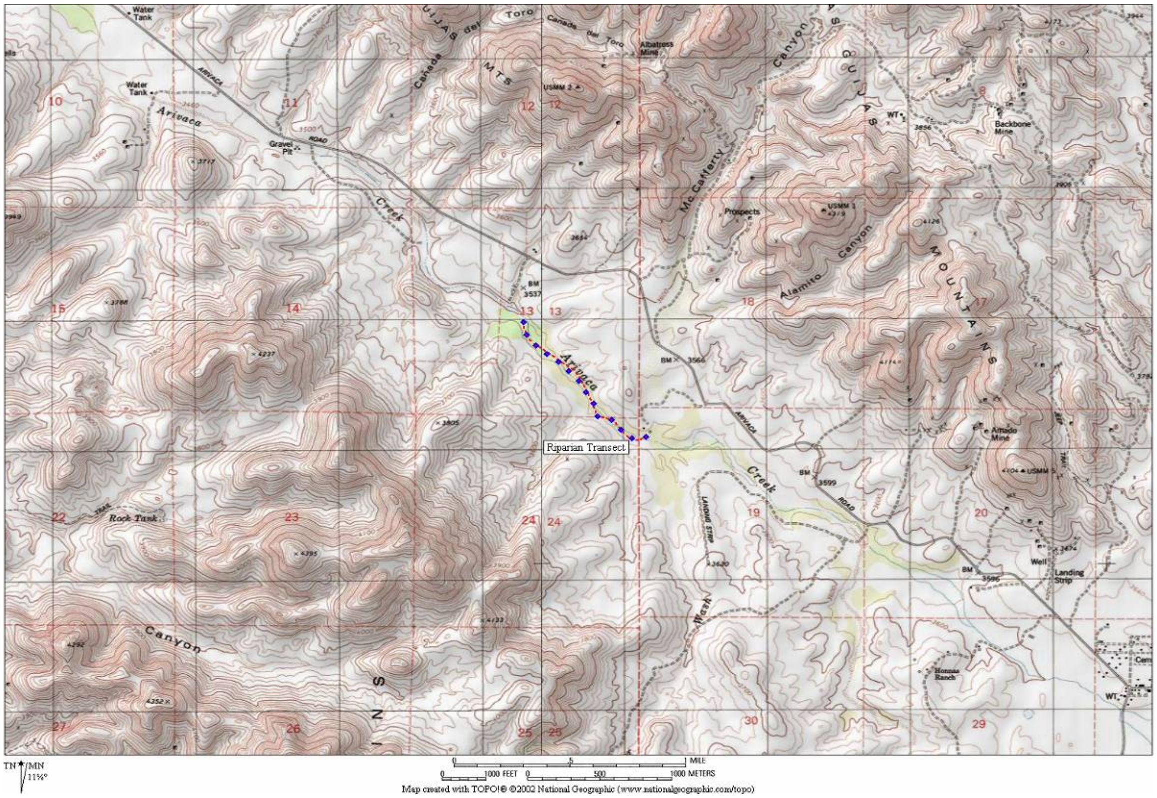
Appendix 1.  Maps of study sites in southeastern Arizona providing detailed views of each study sites.  See Figure 3 for an overview of the study area.

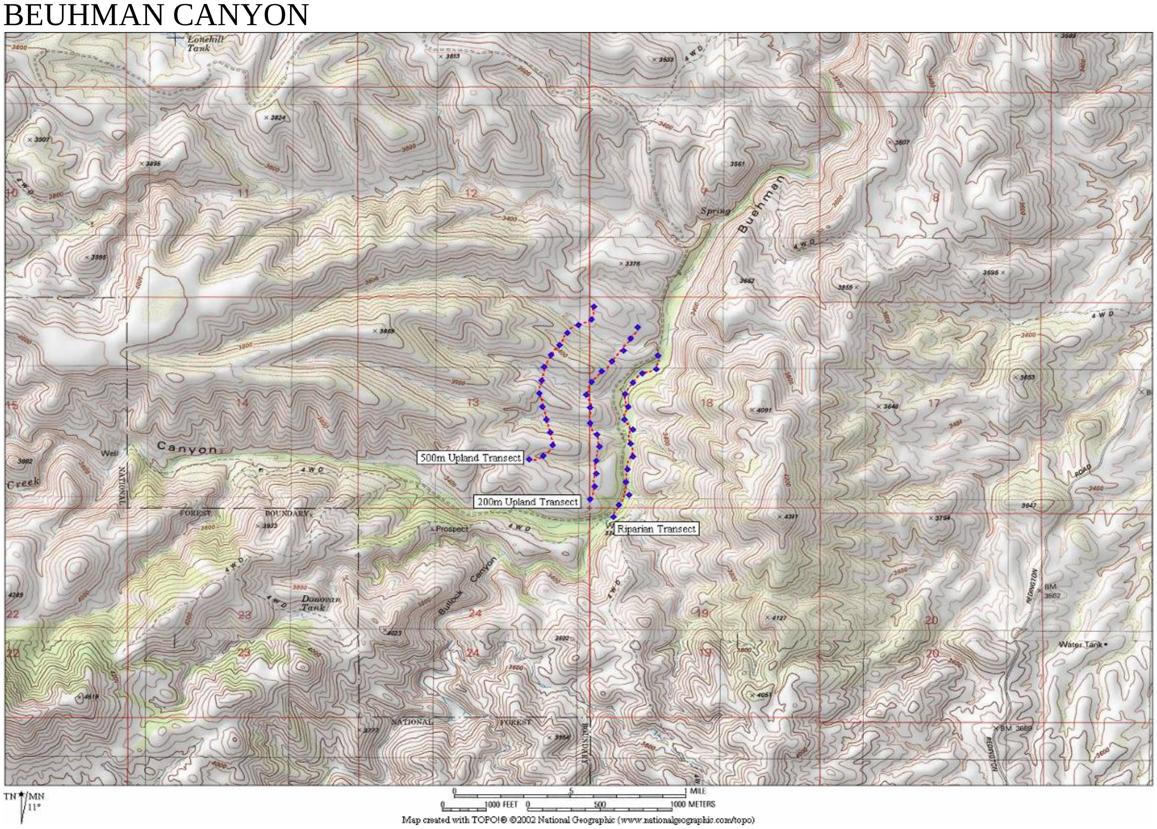
ARAVAIPA CANYON



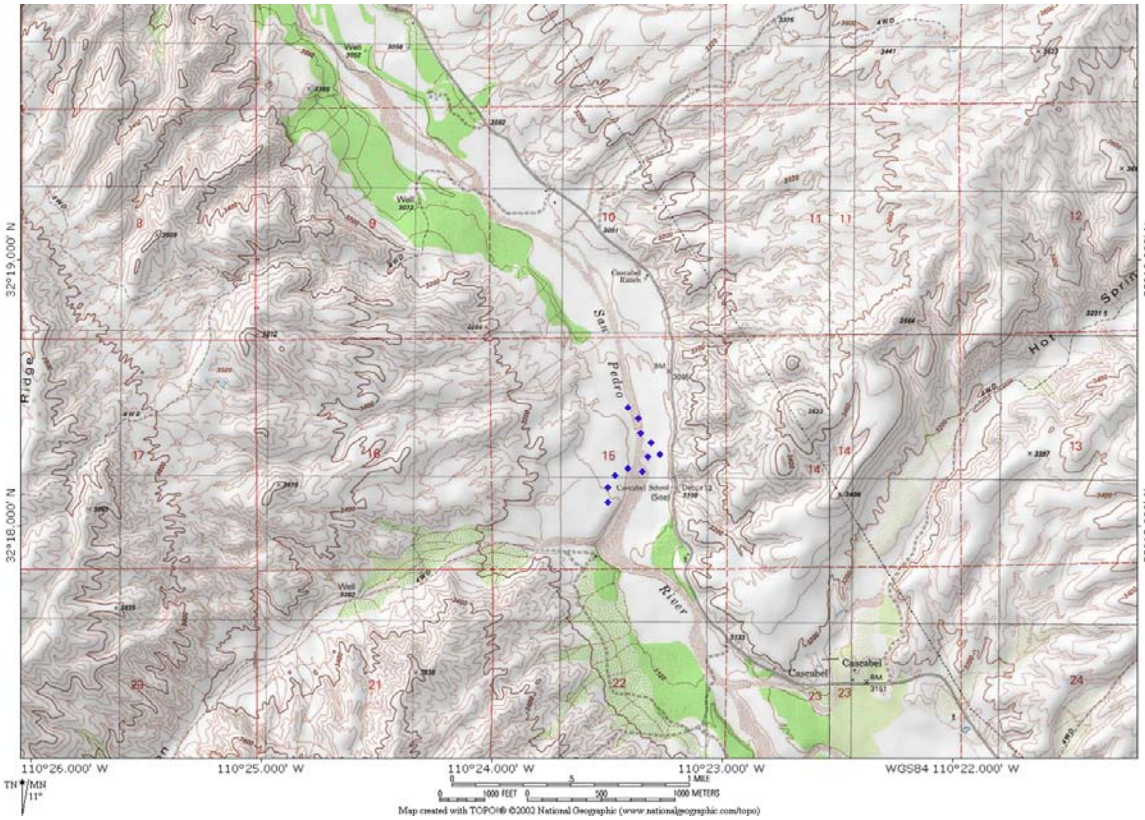
ARIVACA CANYON



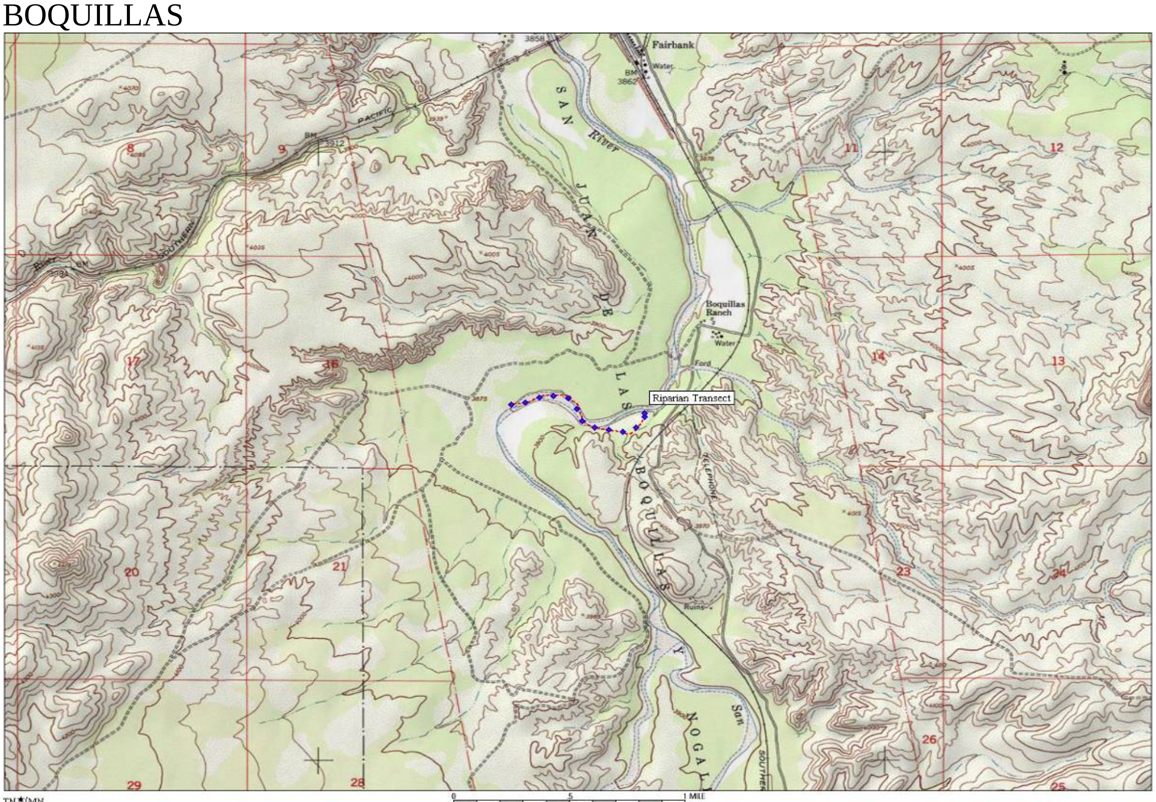

BEUHMAN CANYON



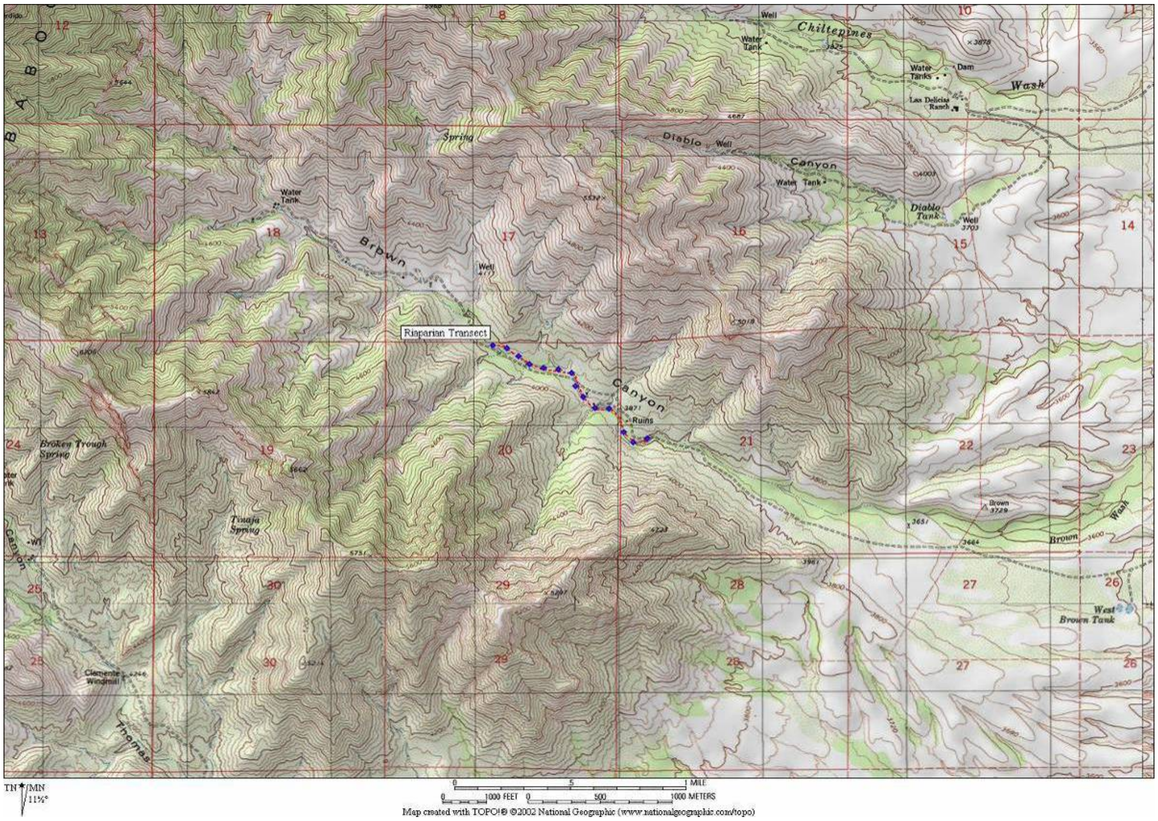
CASCABEL



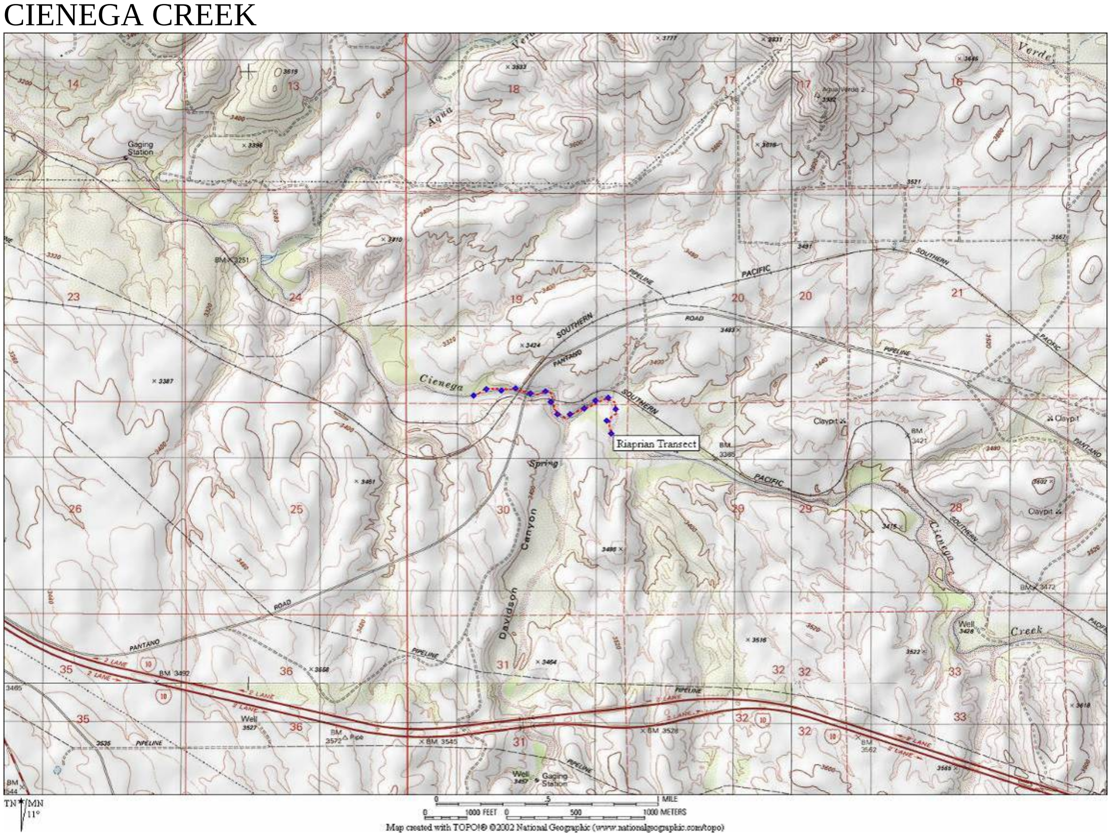

BOQUILLAS



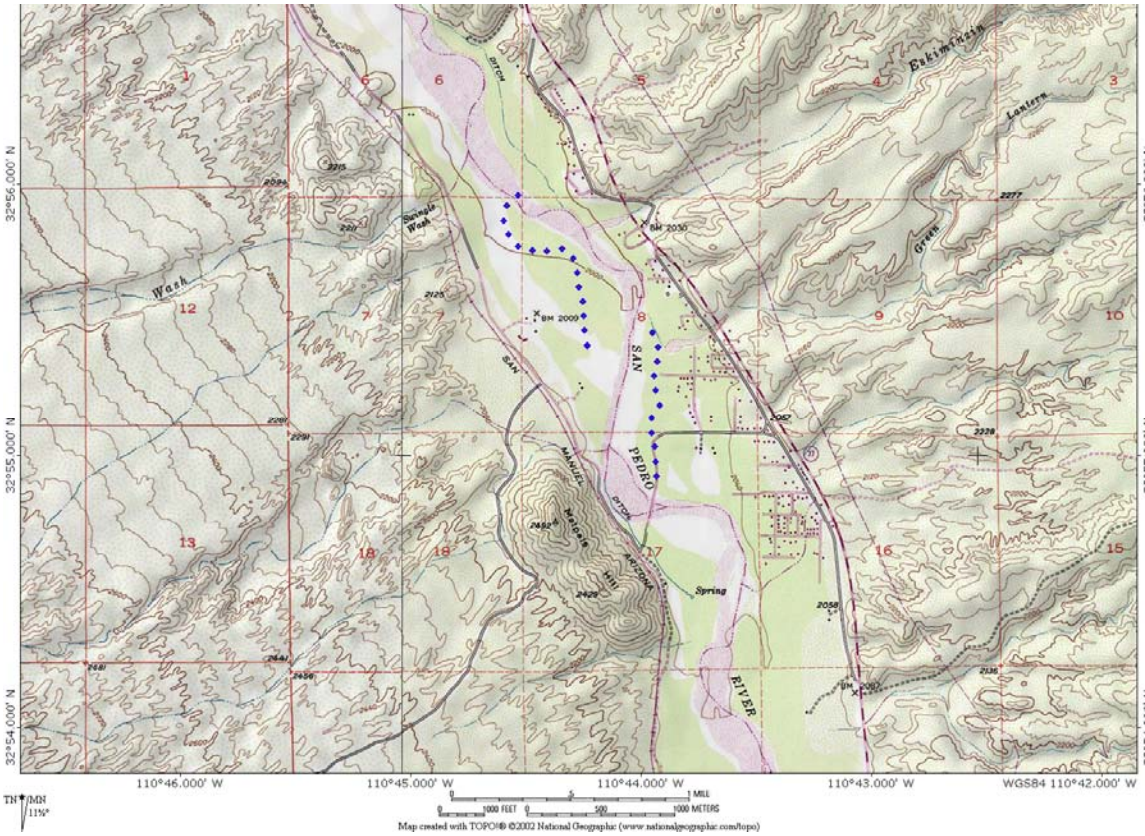
BROWN CANYON



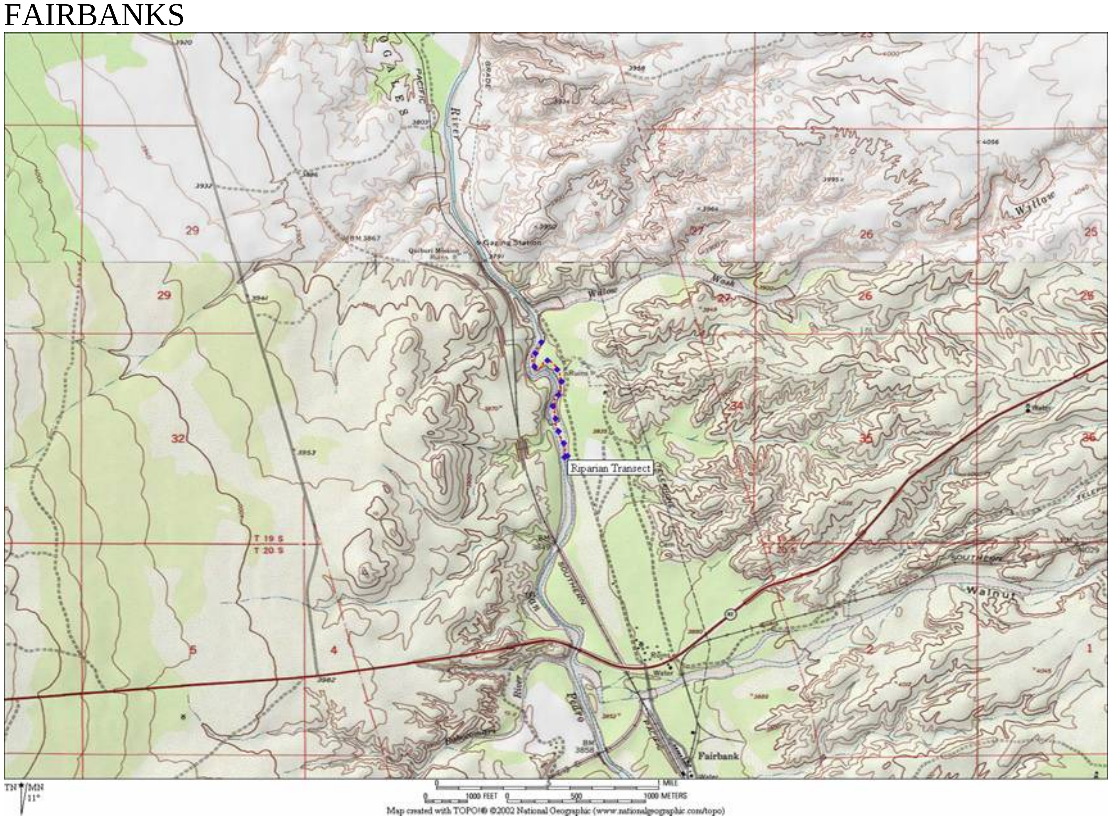

CIENEGA CREEK



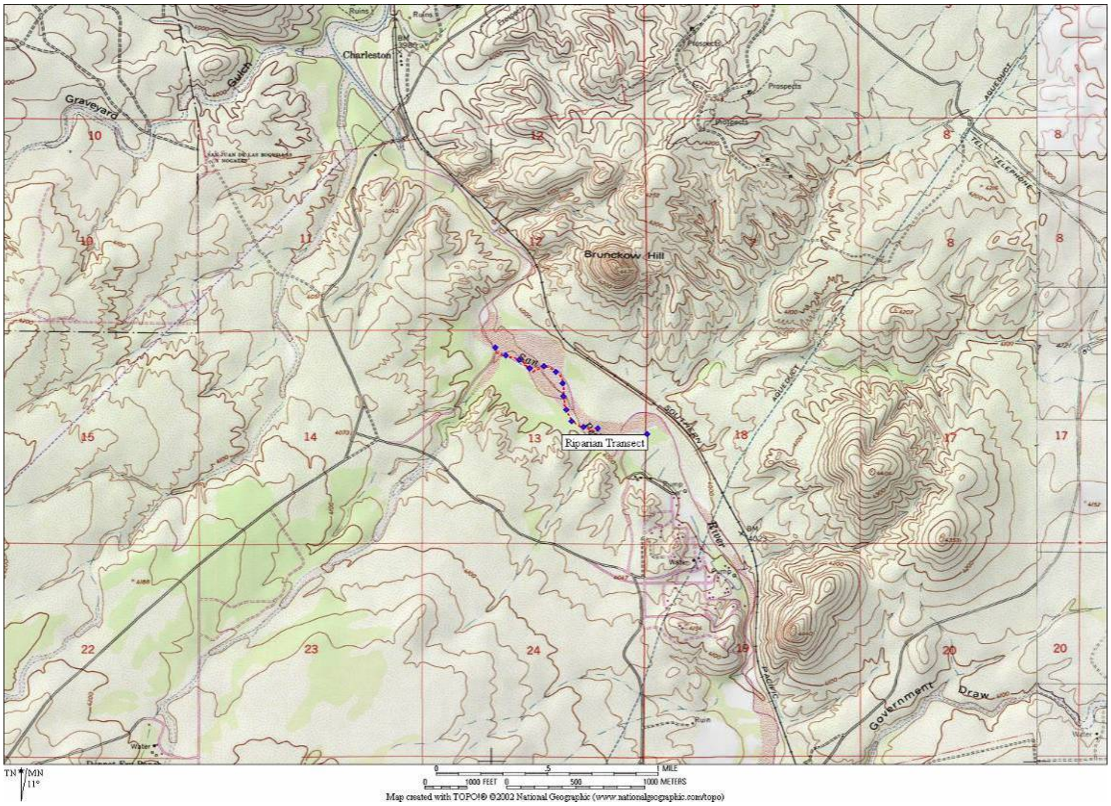
DUDLEYVILLE EAST AND WEST



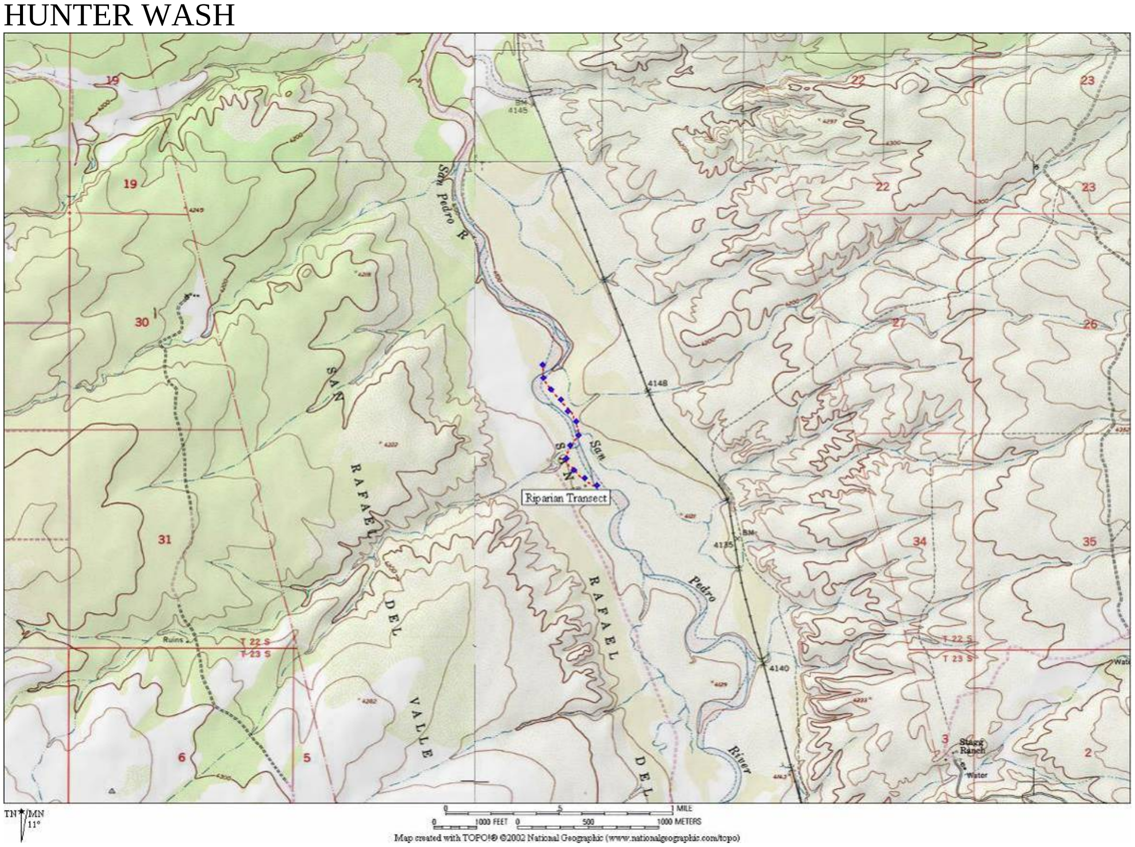

FAIRBANKS



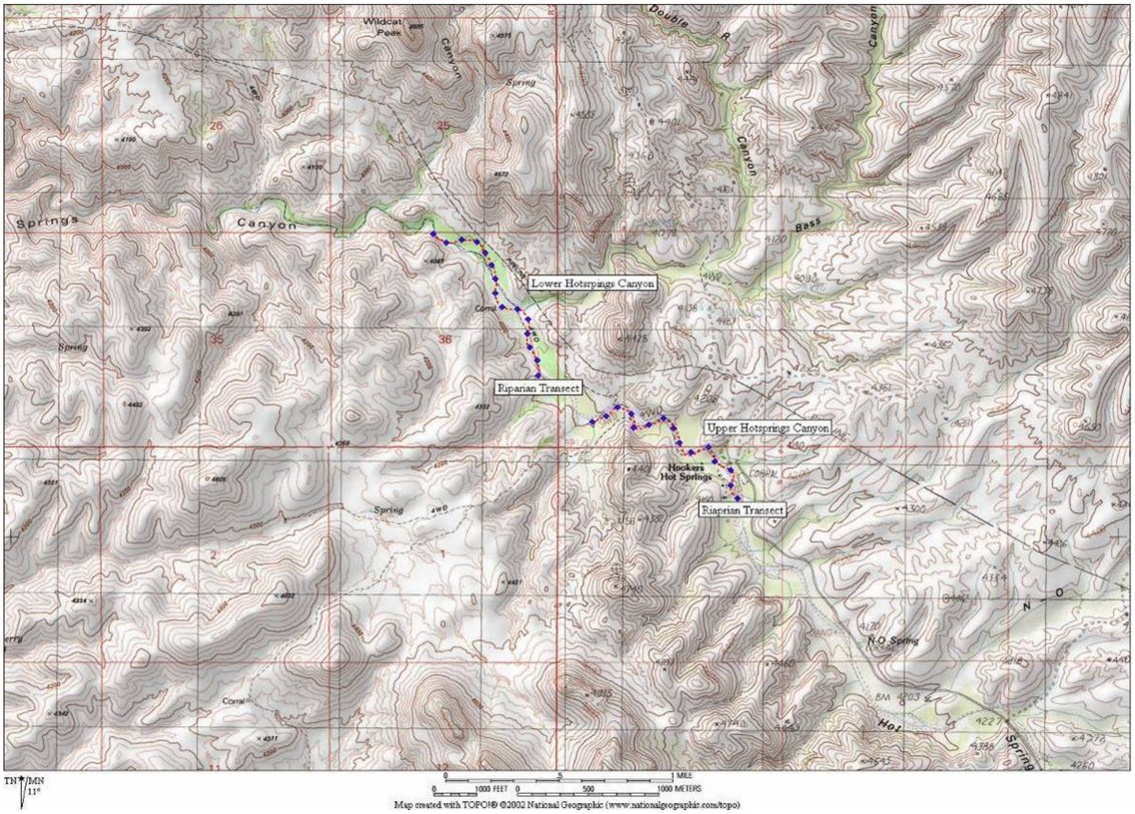
GRAY HAWK



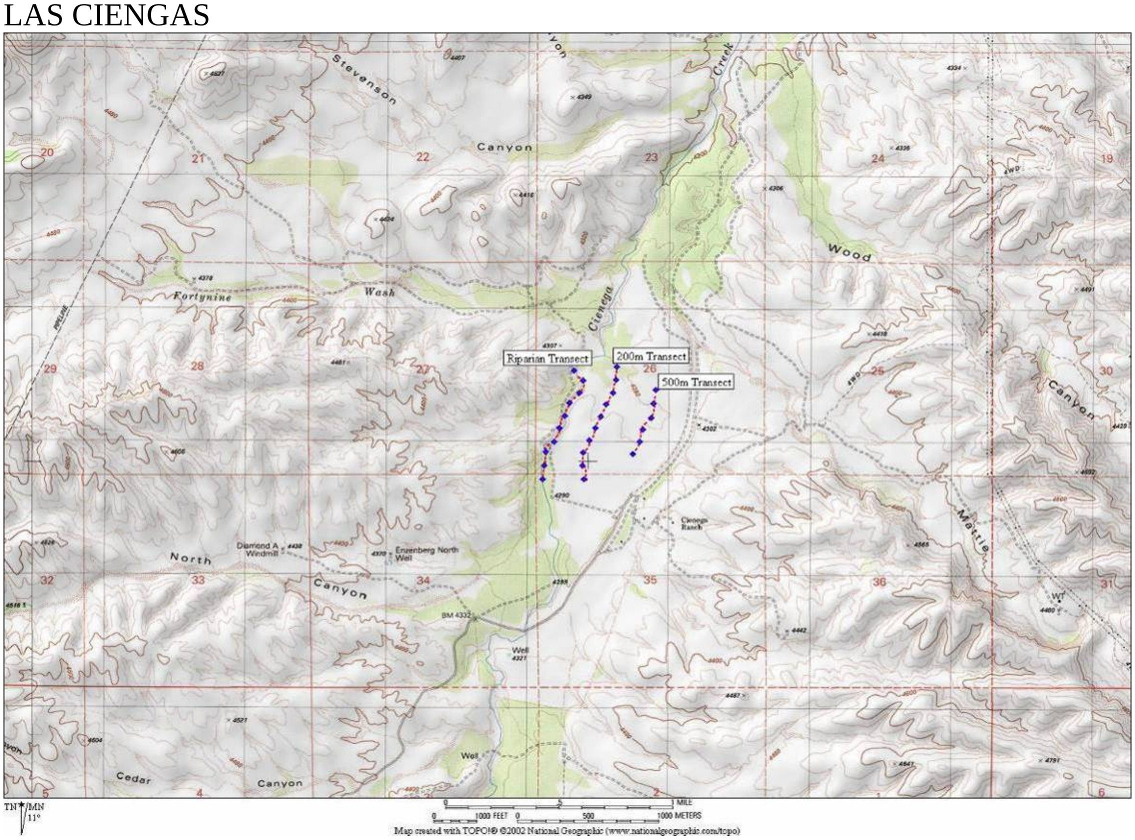

HUNTER WASH



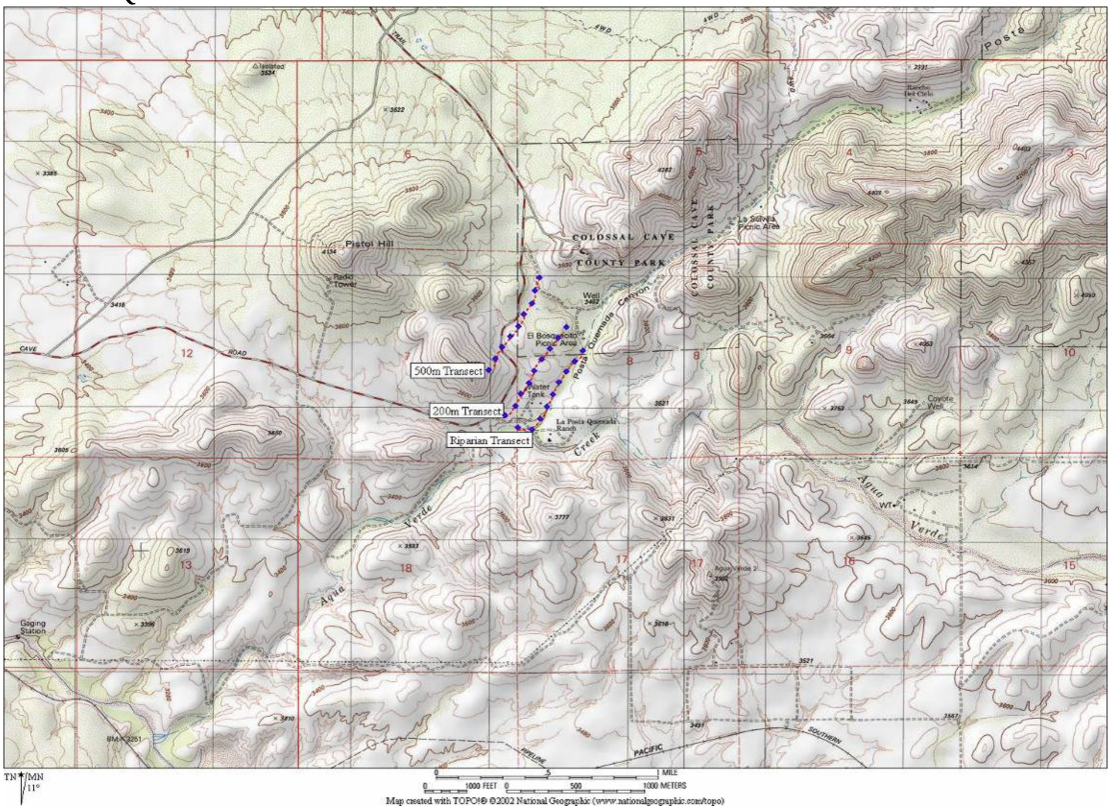
LOWER AND UPPER HOT SPRINGS



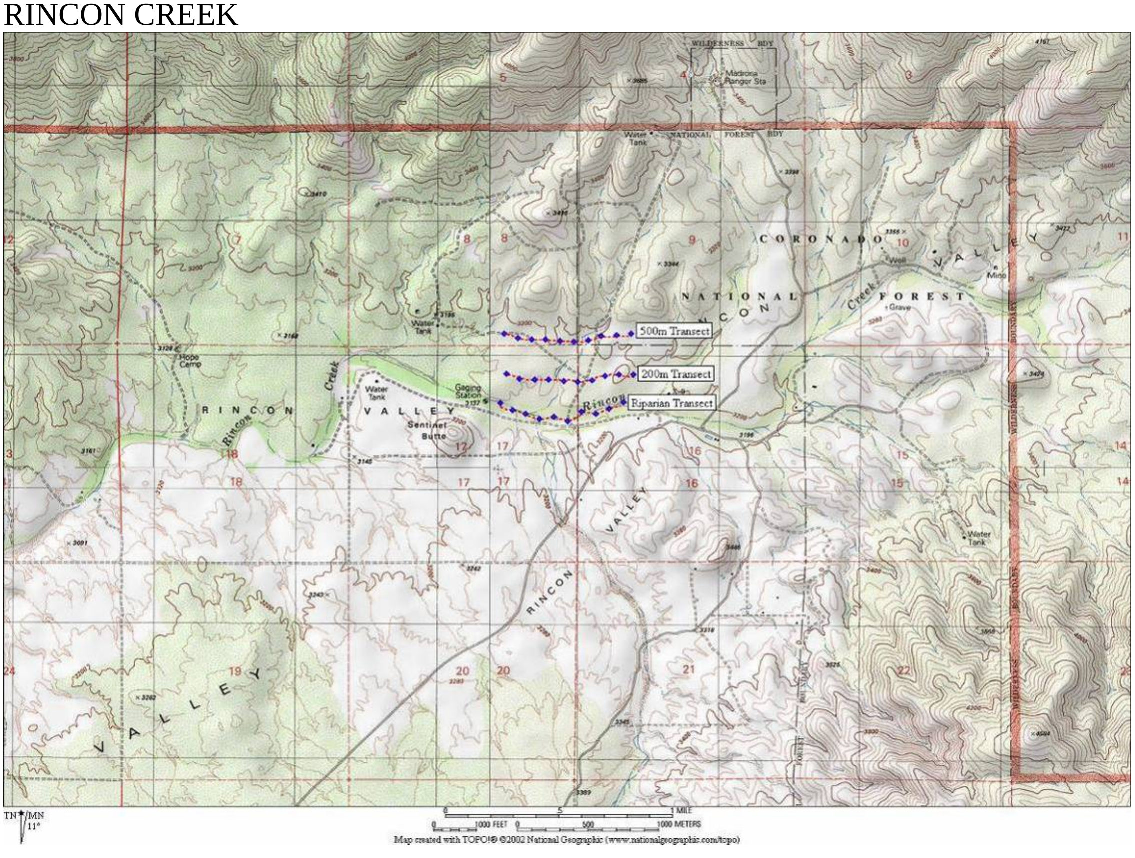

LAS CIENGAS



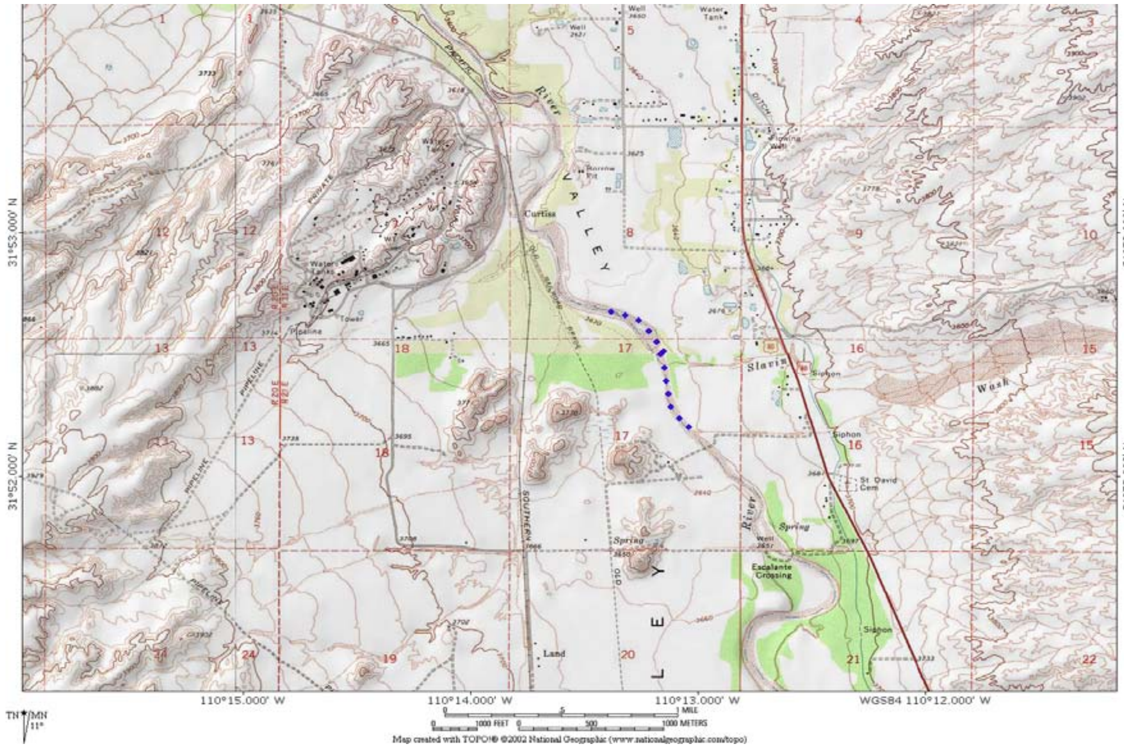
POSTA QUEMADA



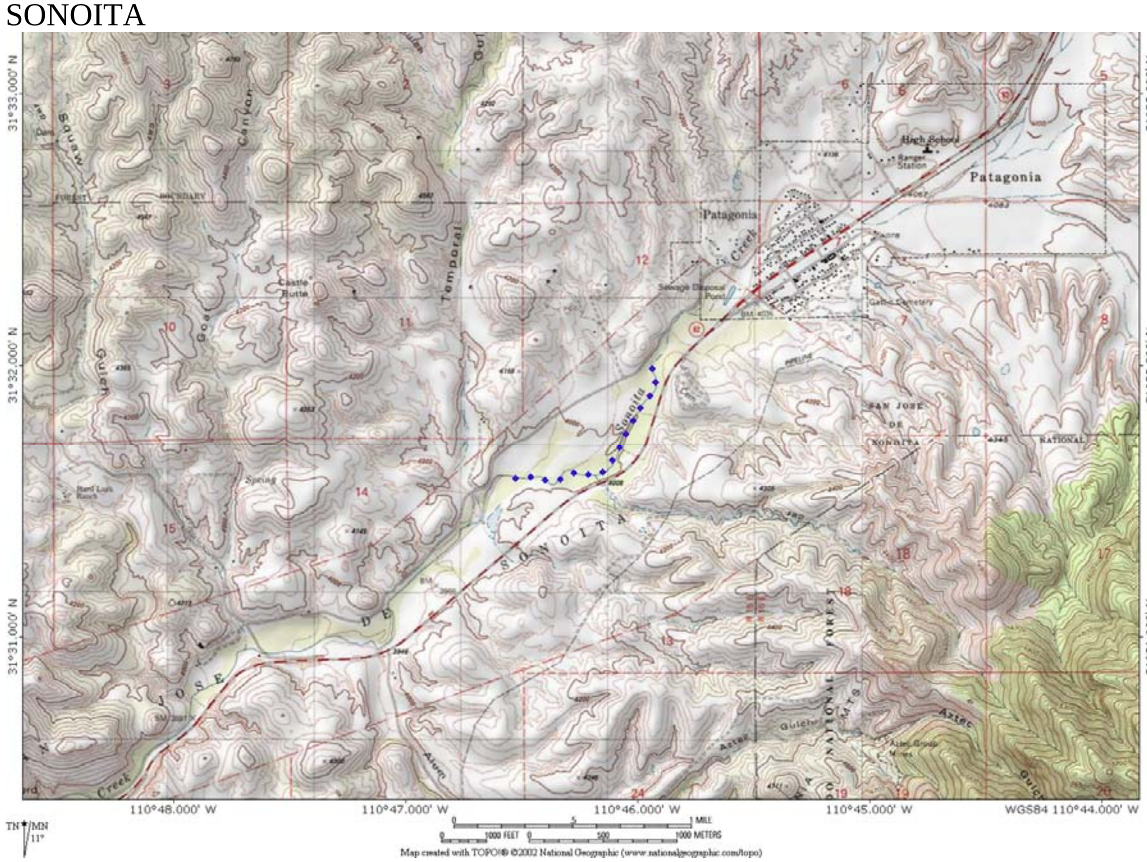

RINCON CREEK



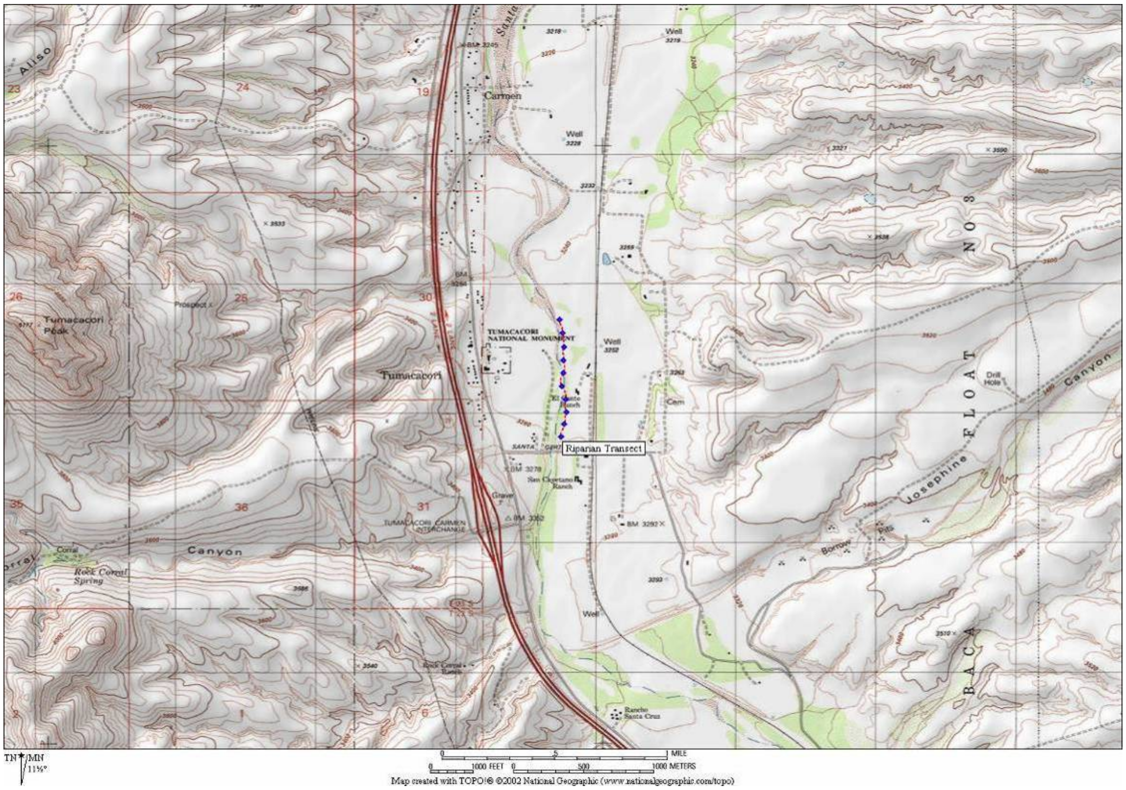
SAINT DAVID



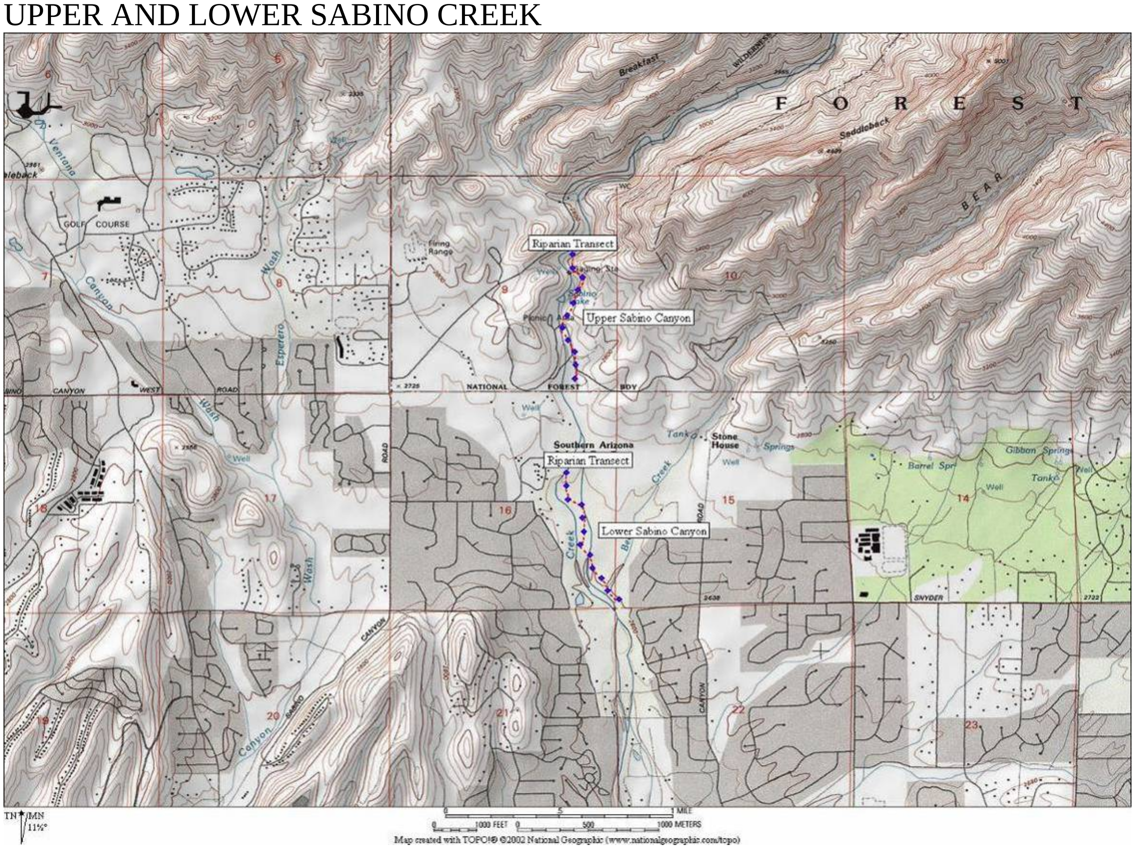

SONOITA



TUMACACORI




UPPER AND LOWER SABINO CREEK



UPPER CIENEGA CREEK